Statistics of Amplitude and Fluid Velocity of Large and Rare Waves in the Ocean

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by

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Abstract

The understanding of large and rare waves in the ocean is becoming more important as these rare events are turning into more common observances. In order to design a marine structure or vehicle to withstand such a potentially devastating phenomenon, the designer must have knowledge of extreme waves with return periods of 50 and 100 years. Based on satellite radar altimeter data, researchers have successfully predicted extreme significant wave heights with the return periods of 50 and 100 years. This thesis extends their research further by estimating the most probable extreme wave heights and other wave statistics based on spectral analysis. The same technique used for extreme significant wave height prediction is applied to extrapolation of corresponding mean wave periods, and they are used to construct two parameter spectra representing storm sea conditions. The prediction of the most probable extreme wave heights as well as other statistical data is based on linear theory and short term order statistics. There exists sufficient knowledge of second order effects on wave generation, and it could be applied to a logical progression of the simulation approach in this thesis. However, because this greatly increases computation time, and the kinematics of deep sea spilling breakers are not yet fully understood for which substantial new research is required, the nonlinear effects are not included in this thesis. Spectral analysis can provide valuable statistical information in addition to extreme wave height data, and preliminary results show good agreement with other prediction methods including wave simulation based on the Pierson-Moskowitz spectrum.

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List of Variables and Acronyms

Variable / Acronym	Definition	Units
adjrsquare	Degree-of-freedom Adjusted Coefficient of Determination	
CDF	Cumulative Distribution Function	
D	Decorrelation time scale for observations of H_s	hours
dfe	Degrees of Freedom	
Extreme H_{prob}	Most probable extreme wave height	meters
F(x)	Distribution function	
f_{max}	Upper bound of frequency domain in FFT	Hz
FT1	Fisher-Tippet Type 1 distribution function	
$H_{extreme}$	2 x maximum crest height	meters
$H_{extreme\_max}$	Maximum crest-to-trough height	meters
H_s	Significant wave height	meters
H_s100	Extreme significant wave height with the 100 year return period	meters
H_{s50}	Extreme significant wave height with the 50 year return period	meters
IDM	Initial Distribution Method	
K	Rayleigh distribution correction value	
lc	Location parameter	
m_0	Zeroth moment (spectral moment)	
m_2	Second moment (spectral moment)	
N_{POT}	Number of selected POT data points	
N_Y	Number of years covered by POT	
POT	Peak Over Threshold	
RMS	Root Mean Squared	
RMSE	Root Mean Squared Error	
rsquare	Coefficient of Determination	
S or S_ζ	Wave elevation or height spectrum	
S_a	Fluid acceleration spectrum	
SAR	Synthetic Aperture Radar	
sc	Scale parameter	
sh	Shape parameter	
SOE	Safe Operating Envelope	
S_{s50}	Extreme significant steepness with the 50 year return period	
sse	Sum of Squares Due to Error	
S_v	Fluid velocity spectrum	
T_{100}	Number of hours in 100 years	
$T_{design\ wave}$	Wave period associated with design wave	seconds
T_m	Mean wave period	seconds
T_{m50}	Mean wave period with the 50 year return period	seconds
T_{modal}	The period at which a wave elevation spectrum has its highest energy density value	seconds

T_p	Peak wave period	seconds
T_z	Zero-crossing period	seconds
T_{z50}	Zero-crossing period with the 50 year return period	seconds
W2P	Weibull 2-parameter distribution function	
WAM	Wave Model	
x	Significant wave height as defined in a distribution function	meters
α	Location parameter	
β	Scale parameter	
θ	Shape parameter	meters
λ_{min}	Minimum wave length used to determine f_{max}	meters

1 Introduction

The ocean environment is unforgiving as it always has been. As human endeavor reaches deeper and deeper into the open ocean whether for transporting world commerce or searching for an oil field or applying national security interests, extreme conditions known to have existed only in the sailor's legend have recently made frequent news headlines around the globe. Over the last two decades, some 200 supercarriers, each longer than 200 meters, have been lost at sea due to extreme large waves also known as 'freakish' or 'rogue' waves (Figure 1.1) [20]. In February 1995, the Queen Elizabeth II faced a 29 meter high rogue wave in the North Atlantic during a hurricane, and another 26 meter high rogue wave was measured at the Draupner oil rig in the North Sea on January 1995 [32]. Although these extreme and rare waves are becoming observed more commonly, the dynamics behind them are not yet fully understood.

Figure 1.1: Freak wave [4]

1.1 Motivations

The threats of rogue or extreme waves are real (Figure 1.2), and the European Union has initiated scientific projects called MaxWave and WaveAtlas to better understand this phenomenon [26]. These two ongoing projects revolve around analyzing the extensive Synthetic Aperture Radar (SAR) data collected by the European Space Agency's (ESA) ERS-1 and ERS-2 satellites to study extreme waves. More and more environmental studies are being conducted using remote sensing data such as the ones

measured by various satellite missions including GEOSAT, TOPEX/Poseidon and ERS, and they offer a wide range of oceanic data that was not available until now. However, we do not yet have detailed measurements of most individual waves.

Figure 1.2: A vessel damaged by a giant wave [26]

In order to understand extreme wave events, an extensive amount of data with sufficient spatial and temporal coverage is required. Until recently, some of the measurements involving wave height and wind speed were mainly dependent on sparsely placed in-situ instruments such as the Waverider buoys manufactured by Netherlands' Datawell. Although these instruments can provide accurate measurements, their limited observable areas as well as often being close to shore restrict their exposure to extreme deep water weather phenomena. Some open water measurements have been made by ocean going vessels, but since these vessels normally stay on routes that are safe from extreme weather conditions like hurricanes, their measurements are not so useful in studying extreme events. Furthermore, the sheer size of world oceans renders any in-depth environmental observations based on in-situ measurements almost impossible. With its truly global coverage, the remote sensing data from satellites have become an indispensable source of oceanic data for extreme environmental studies.

Alves and Young [1][2] have done extensive research on estimating extreme significant wave heights based on these satellite radar altimeter data, and this thesis is built on their findings. The missions flown by GEOSAT, TOPEX/Poseidon, and ERS satellites covered the entire globe (ERS-2 is still active), and these satellites have provided valuable data that are still being analyzed today. The biggest shortcoming of each satellite mission, however, was that satellite instrument resolution was not fine

enough to measure individual wave crests and troughs. Only significant wave height (about equal to the average height of the one-third highest waves in a region) could be determined.

1.2 Objectives

The ultimate goal of this thesis is to provide statistical data of amplitude and fluid velocity of large and rare waves based on the satellite measured remote sensing data using linear theory and spectral analysis. Based on Alves and Young's [1][2] extreme significant wave height data and corresponding mean wave period based on numerical simulation, two parameter storm sea spectra are constructed. These spectral data can be used as a quick reference guide for naval engineering application, especially during the initial design concept exploration stage. In addition, the data can be used for preliminary studies in preparation for any deep water experiments involving extreme wave observations. The following is the list of extreme environmental data that are constructed in this thesis.

1. Extreme significant wave height prediction by Alves and Young [1][2]
2. Most probable extreme wave height (2 x amplitude) prediction based on the Fisher-Tippett Type 1 (FT1) and Initial Distribution Method (IDM) for extreme significant wave height extrapolation
    a. Bretschneider spectrum using the Weibull 2-parameter (W2P) distribution functions for mean wave period extrapolation
    b. Ochi's hurricane-generated sea spectrum using the W2P distribution functions for mean wave period extrapolation
    c. Bretschneider spectrum using the average of FT1 and W2P distribution functions for mean wave period extrapolation
    d. Ochi's hurricane-generated sea spectrum using the average of FT1 and W2P distribution functions for mean wave period extrapolation
3. Simulated extreme wave data using the Pierson-Moskowitz spectrum (otherwise noted, each simulation run is for a 3 day duration) using a Gaussian probability distribution for sea surface elevation with no nonlinear wave interactions.

a. The most probable extreme wave amplitudes for duration periods of 3 hours and 3 days.
b. The most probable extreme wave heights as measured from crest to trough
c. Mean zero-crossing wave periods
d. Mean minimum wave length (Mean minimum wave length is measured from the waves that exceed a threshold value of extreme significant wave height given for each simulation run.)
e. RMS vertical velocity
f. RMS vertical acceleration

The most probable extreme wave heights with the return periods of 50 and 100 years are also known as design wave heights, and they are often used as one of key design parameters. It has been shown that the impact of design wave height on cost is significant. As an example, for a typical North Sea production platform, a one meter increase in the design wave height resulted in the cost increase of £1 million [35]. Therefore, an accurate database of design wave heights can be beneficial during the initial design concept exploration stage.

Furthermore, ocean wave amplitude spectra corresponding to storm sea conditions can be valuable since they can provide additional statistical information that normally would not be available explicitly from the satellite radar altimeter data. For example, slope, directional and wave particle velocity spectra can be useful in seakeeping analysis of a ship or a platform that is expected to operate in extreme ocean environments. Especially for military applications and high speed high performance vessels, the spectral information could effectively drive design parameters and establish Safe Operating Envelope (SOE) that is directly related to the safety of ship and its crew.

Wave periods also play an important role in spectral analysis. However, reliable wave period data for extreme conditions with the return periods of 50 and 100 years are rare. In this thesis, wave periods corresponding to extreme H_s are estimated using an extrapolation technique that is similar to what Alves and Young [1] used for the estimation of extreme H_s.[1] Also, wave simulation based on the Pierson-Moskowitz

[1] The extreme H_s that are mentioned in the remaining chapters refer to the extrapolated data by Alves and Young [1][2] although they may not be explicitly stated as such.

spectrum and Fast Fourier Transform technique (Section 3.4) is used for wave periods estimation and validation.

All the data are tabulated in Appendices A and B for the following two areas that are selected based on the severity of sea states: the North Pacific (21^o-45^o N, 161^o E-149^o W) and the North Atlantic (37^o-57^o N, 19^o-49^o W).

2 Environmental Data Background

In this section, the data used for prediction of the most probable extreme wave heights or extreme H_{prob} are discussed. The satellite radar altimeter data used by Alves and Young [1][2] are summarized, and it includes data collection, processing and validation methodologies. The method used for the extreme H_{prob} prediction in Section 3.3 requires spectral analysis. For this reason, the mean wave period, T_m, data based on the WAM model is used, and this is discussed in Section 2.4.

2.1 Satellite Radar Altimeter Data

Extreme significant wave height prediction by Alves and Young [1][2] is based on the satellite radar altimeter data from the following missions.

GEOSAT: November 1986 – January 1990

TOPEX: September 1992 – October 1995

ERS1: August 1991 – October 1995

Deep water environmental data are almost nonexistent due to the fact that extreme events such as freak waves are localized phenomena, and no consistent methods of observing them are currently in place. Also, the difficulty of designing such a device that can withstand the harsh operating conditions of such phenomena and function reliably further complicates the matter. The limitations of spatial coverage with in-situ instruments have been largely overcome by satellites as their radar altimeter data can provide a wealth of environmental data that are truly global in nature.

The satellite data are not without limitations, however. Its data resolution needs to be further improved, and it is already taking place via employment of Synthetic Aperture Radar (SAR) (Section 2.2.3). Furthermore, because satellites and associated measuring equipment have limited life span, most of the satellite missions by themselves do not provide adequate temporal coverage required for any type of statistical analysis on the weather phenomenon of an interest. The shortcoming due to limited temporal coverage can be, however, overcome by grouping them together as it has been done by

Alves and Young [1][2]. Each of the three missions listed above are briefly summarized in the following sections.

2.1.1 GEOSAT

GEOSAT [29] was launched in March 1995 and consisted of a one and a half year long classified mission for the United States Navy, which was followed by GEOSAT's scientific Exact Repeat Mission (ERM) from November 8, 1986 to January 1990 when both on-board tape recorders failed. The data used by Alves and Young [1][2] were from the last approximately three years of ERM [38]. The satellite was gravity gradient stabilized and had two tape recorders with 17 day exact repeating orbit (Figure 2.1) with a ground track accuracy of approximately 1 km. Figure 2.1 shows only those areas with reliable data. The satellite intended design life was 3 years although its service extended more then 3 years. Covering latitudes ± 72 degrees, it orbited between 760 and 817 km above sea level while providing precision of ± 5 cm of significant sea surface height. It was designed and built by Johns Hopkins University Applied Physics Laboratory and employed a pencil beam nadir looking (directly below) radar altimeter to measure wind speed and significant wave height along the ground tracks.

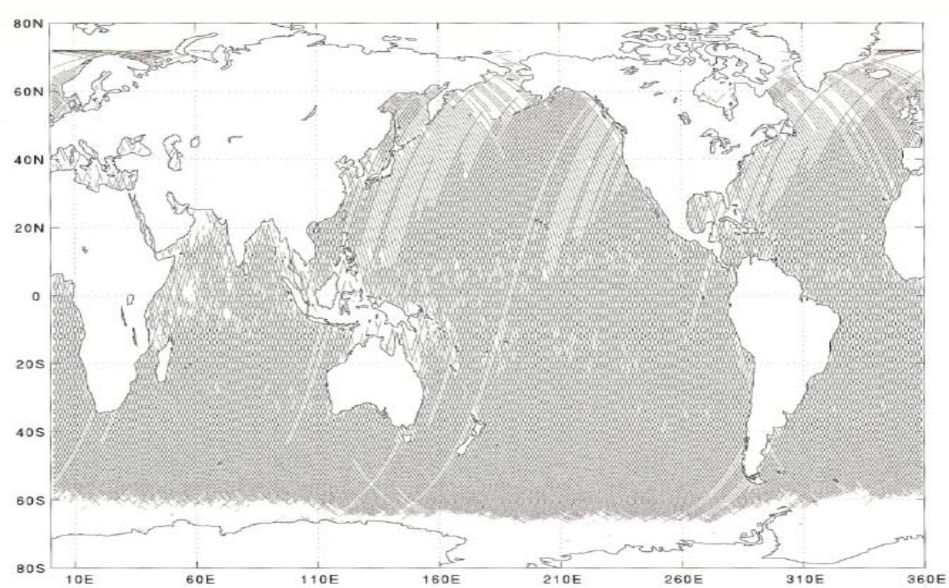

Figure 2.1: Ground track pattern for the 17 day repeat cycle of the GEOSAT satellite between November 8, 1986 and November 24, 1986 [38]

2.1.2 TOPEX/Poseidon

TOPEX/Poseidon [16] was the first space joint mission specifically designed for the study of world's ocean circulation by the United States (NASA) and France (the French Space Agency, CNES). Launched in August 10, 1992, it used radar altimeter to make measurements since September 23, 1992. Some of the improved features over GEOSAT were: first dual-frequency space-borne radar altimeter, a three-frequency microwave radiometer, and an optimal Earth's gravity model and multiple tracking systems used for precision orbit determination. It orbited the Earth at an altitude of 1,336 km with a repeat cycle of 10 days within ± 1 km of the ground tracks.

2.1.3 ERS1

ERS-1 (European Remote-sensing Satellite) [15] was the first ESA (European Space Agency) program in Earth Observation with a specific mission objective of providing environmental monitoring particularly in microwave spectrum, which was not just for ocean environments but for over the land observations as well. Launched in July 17, 1991, the satellite employed C-band Synthetic Aperture Radar (SAR) that improved data resolution. In 1993, ERS-1 differential SAR interferometry demonstrated a 1 cm range precision. ERS-1 provided global wind and wave field data at high spatial and temporal resolution, and the mission ended on March 10, 2000 when the onboard attitude control system failed. During its mission (about 8 ½ years) ERS-1 generated approx. 800,000 radar screens. It followed sun-synchronous near-circular polar orbit at altitude in the range of 1,200 to 1,400 km with a repeat period of 9.916 days (normally referred to as a 10-day repeat period).

2.2 Satellite Radar Altimeter Data Processing

In Section 2.2, some of the detailed discussions focus on GEOSAT and its significant wave height data processing technique although the rest of the discussions apply to all satellite radar altimeter data that include TOPEX/Poseidon and ERS-1.

2.2.1 GEOSAT

Wave Measurements

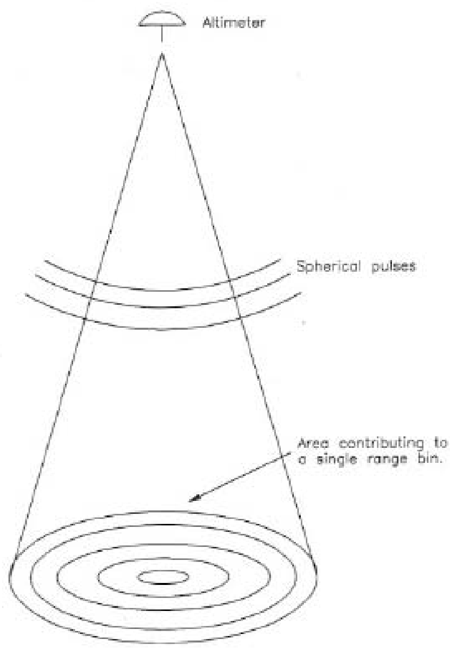

Figure 2.2: Spherical altimeter pulses radiating from the satellite antenna showing areas illuminated in successive range gates [38]

The data processing mechanism onboard GEOSAT is presented in detail in [38] and [41], and the following is a brief summary of these articles. The GEOSAT radar altimeter with single frequency operation mode of 13.9 Hz transmitted 1,000 pulses per second. The pulse radiation as a spherical shell is shown in Figure 2.2. The pulse reflection from the water surface in discrete intervals called "range gates" were sampled, processed and averaged by the satellite. Examples of these returns are shown in Figure 2.3 for two different significant wave heights. Also, from Figure 2.3, it can be seen that as the significant wave height increases the slope of leading edge of the pulse decreases. It is this slope that was used to measure significant wave heights. Once these returns were collected, they were averaged to give a data rate of one per second. Figure 2.4 shows the returns from SEASAT altimeter data, but the process was similar for GEOSAT. The ground speed of GEOSAT was 6.5 km/s, and this corresponded to one data value for every 6.5km along the ground track. It equated to approximately 50,000

observations of wind speed and significant wave height made per day for open ocean areas. Over the ERM, the value reached approximately 45 million observations per day.

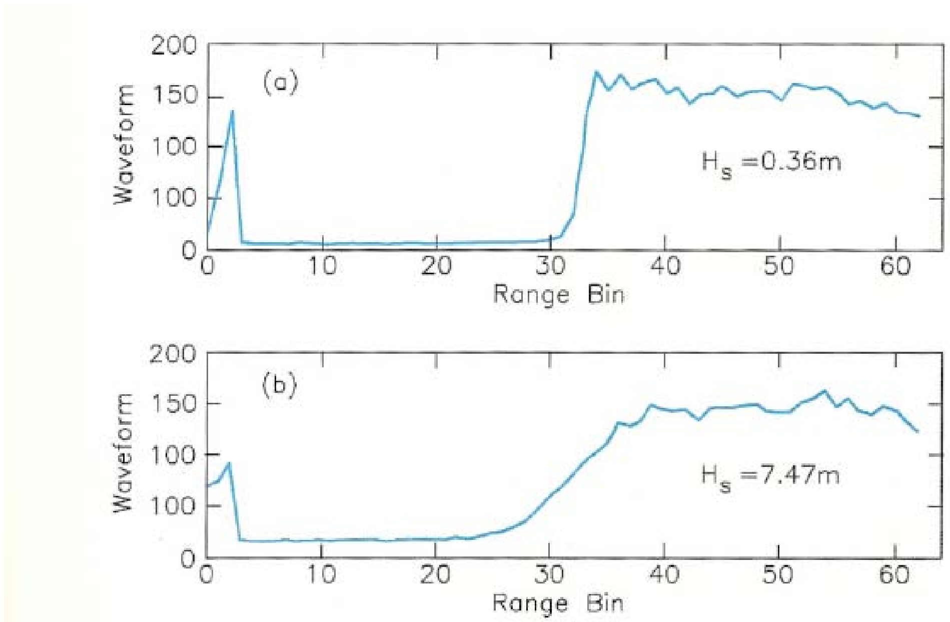

Figure 2.3: Examples of the one second average return pulse from the GEOSAT altimeter for (a) H_s = 0.36 m and (b) H_s = 7.47 m [14]

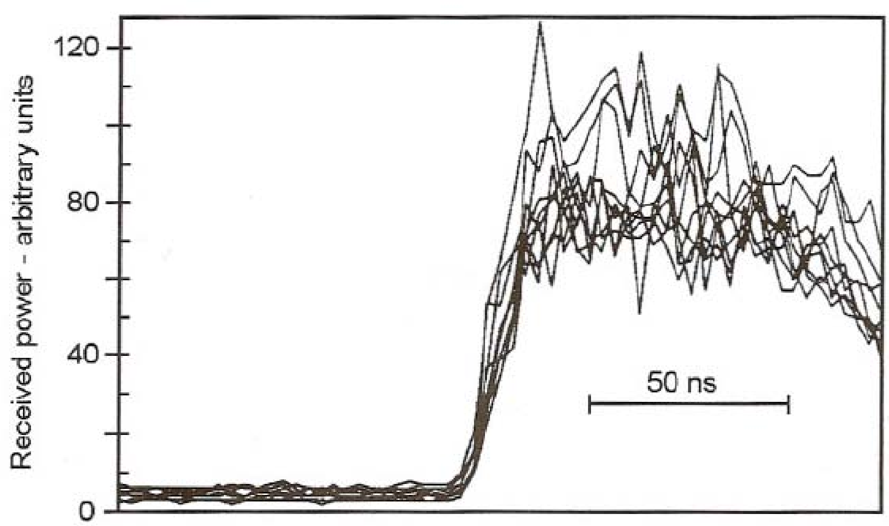

Figure 2.4: Ten successive smoothed returns from the Seasat precision altimeter. Each graph is the average of 50 individual returns (for GEOSAT there are 1000 individual returns) [36]

GEOSAT altimeter data had an accuracy of ±0.5 m or 10% of the significant wave height measured, which ever was greater. Dobson et al. [14] compared GEOSAT altimeter derived values of significant wave height, H_s, with the values from U.S National Ocean Data Center (NODC) buoys. They found that the RMS difference between the two was 0.49 m with mean difference of 0.36 m and that the GEOSAT data were consistently lower than the buoy data. This information was used to calibrate the satellite data as discussed in Section 2.3.

Some of the GEOSAT radar altimeter data contained spikes as shown in Figure 2.5. These data spikes corresponded to the continental boundaries and data over land masses such as islands and exposed reefs. Young [38][40] used two-pass automatic data-checking algorithm to identify and correct the data spikes, and they are summarized below.

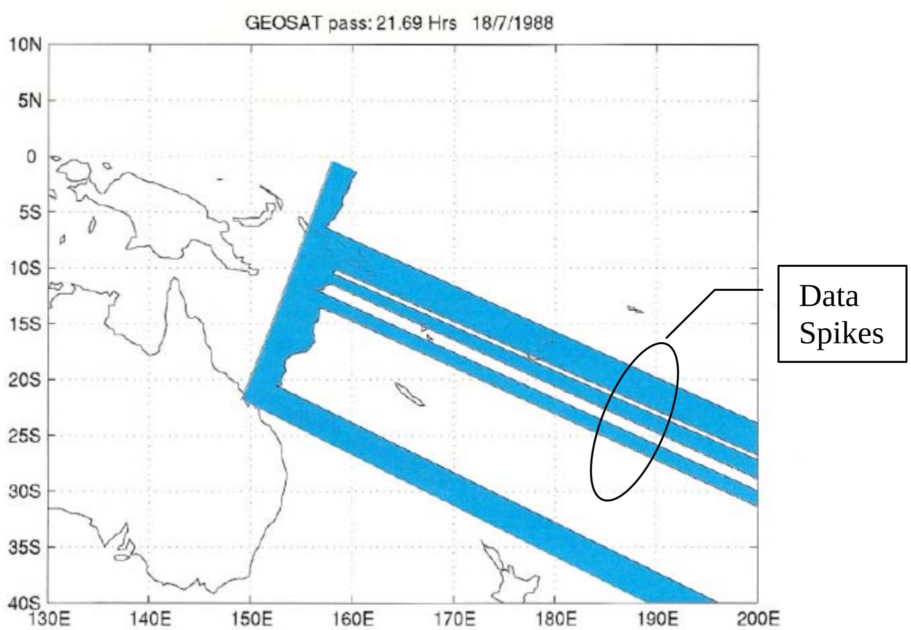

Figure 2.5: Variation in the significant wave height along the "south going" GEOSAT ground track recorded on 18 July 1988 at 21.7 hrs UT. Note the data "spikes" which occur as the satellite passes over isolated islands and reefs in the Coral Sea [38]

<u>Pass 1</u>

1. Any standard deviation of the individual radar pulses were measured against the average of a number of individual radar pulses for H_s, and when this ratio exceeded 0.1 the data was discarded.

2. Any data over the land was discarded using a 1/12 deg land mask.
3. Valid data range for H_s = 0-20m was used.

Pass 2

1. The remaining data were divided into blocks of 50 points and checked for any spatial jumps as this would indicate the data measured over a land mass. Then the mean value of H_s and its corresponding standard deviation, σ_{Hs}, were calculated. If the ratio of standard deviation (block) to the mean value of H_s (block) was greater than 0.5, the entire 50-point block was discarded.
2. Individual data outliers within the 50-point blocks were discarded using the following criterion: $|H_s - H_{s\_mean}|/\sigma_{Hs} > 3$.

Young [37] further validated this technique by visually inspecting sample data sets. Young [37] concluded that technique was conservative, and it discarded some valid data close to land masses. However, this was not an issue for the application of deep water measurements.

2.2.2 TOPEX/POSEIDON

RMS accuracy of a single-pass sea level measurement for TOPEX was 4.7 cm and for POSEIDON, 5.1 cm. Satellite ground tracks remained within ± 1 km of the nominal tracks 98% of time, and data return rate exceeded 98% [16].

2.2.3 ERS-1

The AMI (Active Microwave Instrument) Synthetic Aperture Radar was used for measurements: SAR for image and wave mode, and a scatterometer (SCAT) for wind mode operation [3]. The AMI in wave mode was used to measure the changes in radar reflectivity of the sea surface due to surface waves. An image or “imagettes” size of 5 km by 5 km was taken at intervals of 200 km along the track. These imagettes were then transformed into spectra containing information about wave lengths and directions. The AMI in wave mode operated with the following settings: frequency = 5.3 GHz, incidence

(look) angle = 23 deg, wave direction = 0 to 180 deg, wavelength = 100 to 1000m, direction accuracy = ± 20 deg, length accuracy = ± 25%, spatial sampling: 5 km x 5 km every 200 – 300 km, resolution = 30 m, data rate = 370 kbit/sec, duty cycle = 70% [15].

Although SAR can provide higher data resolution than radar altimeter, the actual algorithm to translate SAR imagettes to workable data is still being researched. Therefore, the radar altimeter data from ERS-1 were used for Young's data [37]. The Radar Altimeter-1 (RA-1), which was a nadir-pointing pulse radar, operated in Ku-band with the following settings: frequency = 13.8 GHz, pulse length = 20 ms, pulse repetition frequency = 1020 Hz, data rate = 15 kbits/sec, two modes of operation: ocean and ice, foot print = 16 – 20 m [15].

2.3 Satellite Radar Altimeter Data Comparison & Validation

Satellite radar altimeter data are very useful for long term climate studies and ocean engineering applications since no other database can offer such extensive spatial coverage. Still, satellites generally have a life span of less than 5 years, and a collection of different satellite missions needs to be obtained in order to derive long term statistics. Furthermore, due to inherent system bias, the satellite data need to be calibrated in order to be of any value. The unprocessed significant wave heights, H_s from GEOSAT, TOPEX/Poseidon and ERS1 satellites were corrected by Young using the calibration results described here [37].

One correction technique involves the use of mean monthly values. Cotton and Carter [13] have compared mean monthly altimeter values of H_s from GEOSAT, TOPEX/Poseidon, and ERS-1 with buoy data. The results show that the use of mean monthly values is an acceptable method for the calibration of such instruments. This has the advantage of not requiring the co-location of buoys (which rarely occurs), and it eliminates any inter-comparison of satellites with temporal and spatial overlaps [37]. Young's study [37] extended Cotton and Carter's correction study [13] by including longer data periods provided by TOPEX/Poseidon and ERS-1, which added greater confidence to the results. These results are discussed next.

2.3.1 Satellite data and buoy data

Young [39] and Young and Holland [38] have shown that a period of 3 years is sufficiently long to form reliable global estimates of mean monthly values of significant wave heights, and the satellite data were validated using buoy data. In [37], the data sets from each satellite mission were processed and organized into squares with 4^o x 4^o grid size. Also analyzed were the data from a total of 16 NDBC (National Data Buoy Center) buoys and the locations of these buoys are shown in Figure 2.6 and Table 2-1. The majority of buoy data shown in Table 2-1 that coincide with GEOSAT mission were obtained with the GSBP (General Service Buoys Payloads) buoy sensor package that determined wind speeds using a vector average while other later sensor packages used a scalar average for wind speed determination. These buoys were selected so that they were not influenced by their proximity to shore. Then the buoy data were partitioned into periods corresponding to each of the three satellite periods, and monthly means were determined for each of these periods. Finally, the mean monthly H_s values of buoy data were compared to the mean monthly H_s values from satellite data and validated by Young [37].

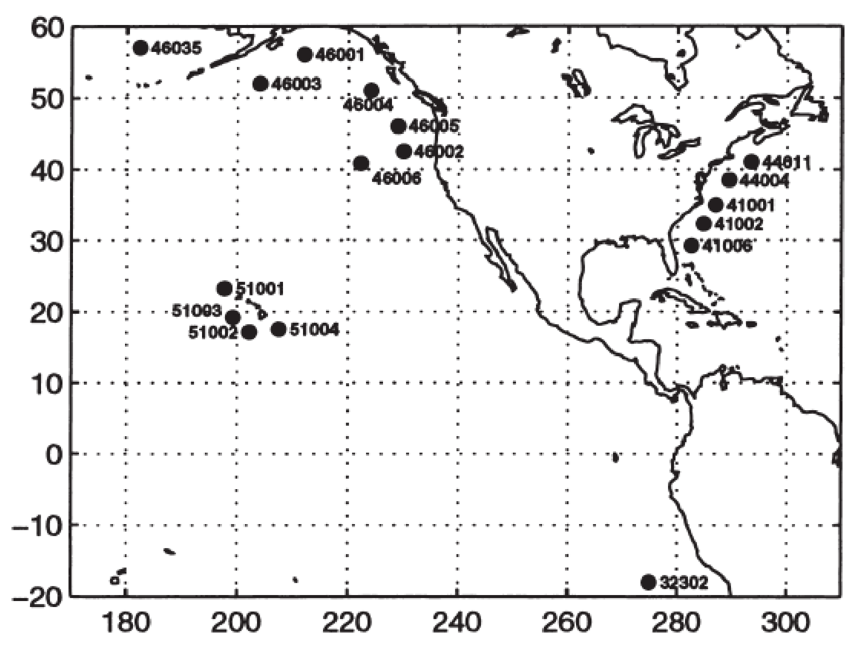

Figure 2.6: Locations of the NDBC buoys used for the comparison of U_{10} (wind speed 10 m above sea surface) and H_s values with GEOSAT, TOPEX and ERS1 satellite altimeter values [37]

Table 2-1: Summary of the NDBC buoy data [37]

Table 1
Summary of the NDBC buoy data. Quantities shown include: the reference number of the buoy, the location of the buoy (latitude, longitude), the number of months of data available during the periods of each of the satellite missions and the percentage of this data collected using the GSBP payload package

Buoy Number	Latitude °N	Longitude °E	GEOSAT		TOPAX		ERS1	
			Months of Data	Percent GSBP	Months of Data	Percent GSBP	Months of Data	Percent GSBP
32302	−18.0	274.9	39	0	32	0	45	0
41001	35.0	288.0	35	97	33	0	44	0
41002	32.3	284.7	35	80	38	0	47	0
41006	29.3	282.6	30	100	37	0	43	0
44004	39.0	289.5	37	89	37	0	46	0
44011	41.1	293.5	38	97	32	0	42	0
46001	56.3	211.7	39	100	34	0	47	4
46002	42.5	229.7	33	100	38	0	48	0
46003	51.9	204.3	34	79	33	0	44	0
46004	51.0	224.0	20	100	0	–	0	–
46005	46.0	229.0	38	100	35	0	46	0
46006	40.6	222.4	35	49	38	0	39	0
46035	57.0	182.4	38	21	38	24	49	24
51001	23.3	197.7	35	100	36	100	46	100
51002	17.2	202.2	32	100	34	100	45	100
51003	19.2	199.2	33	100	38	100	49	100
51004	17.5	207.5	30	100	38	100	49	100
			GSBP = 82%		GSBP = 27%		GSBP = 28%	

Satellite and Buoy Data Comparison

The following Figure 2.7, Figure 2.8 and Figure 2.9 show how satellite and buoy data are correlated, and the plots are for a 4^o x 4^o grid. Young [37] used 203 buoy data points for GEOSAT comparison, and 192 buoy data points were used for TOPEX/Poseidon and ERS-1. All the figures show close correlation between the satellite data and buoy data. Each figure is accompanied by correction equations (2.3-1), (2.3-2) and (2.3-3) that were derived using a least-squares linear regression [37]. Here, it was assumed that the buoy data reflected true significant wave height values. A number of data values available for this comparison were significantly increased by using the mean monthly values that eliminated the measurement collocation requirement in both space and time.

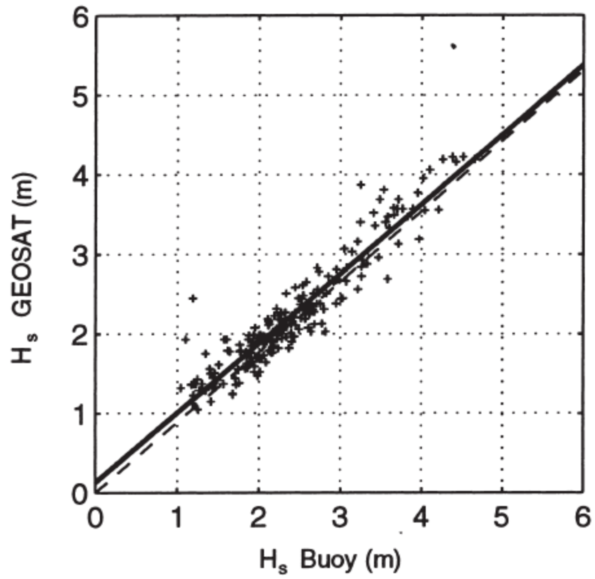

Figure 2.7: Mean monthly values of buoy H_s compared with mean month values of GEOSAT altimeter H_s. The solid line is Equation (2.3-1), and the dashed is the relationship proposed by Carter et al [8] [37]

$$H_s(\text{buoy}) = 1.144H_s(\text{GEOSAT}) - 0.148 \qquad (2.3\text{-}1)$$

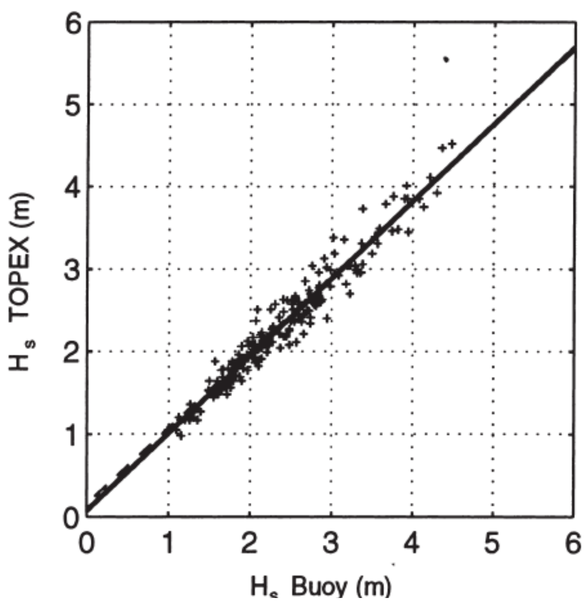

Figure 2.8: Mean monthly values of buoy H_s compared with mean month values of TOPEX altimeter H_s. The solid line is Equation (2.3-2), and the dashed is the relationship proposed by Cotton and Carter [13] [37]

$$H_s(\text{buoy}) = 1.067H_s(\text{TOPEX}) - 0.079 \qquad (2.3\text{-}2)$$

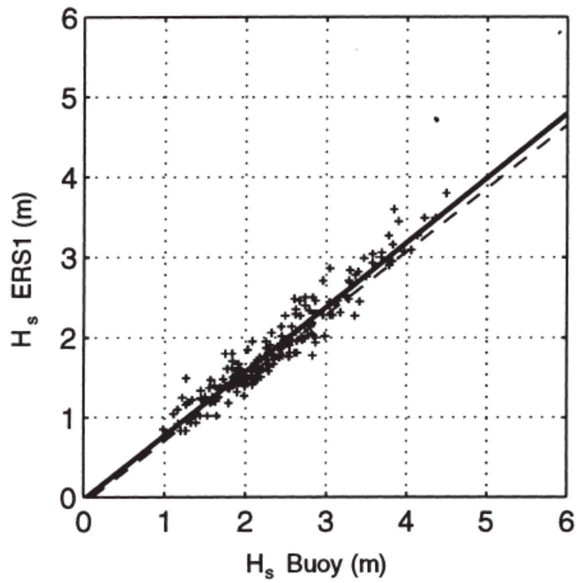

Figure 2.9: Mean monthly values of buoy H_s compared with mean month values of ERS1 altimeter H_s. The solid line is Equation (2.3-3), and the dashed is the relationship proposed by Cotton and Carter [13] [37]

$$H_s(\text{buoy}) = 1.243H_s(\text{ERS1}) + 0.040 \tag{2.3-3}$$

Satellite-Satellite Data Comparison

Young [37] also did cross validations between the Geosat, TOPEX and ERS-1 satellites. A total of 15,095 squares, each measuring 4^o x 4^o, had sufficient passes by each satellite to yield reliable mean monthly values of H_s. For the comparison, the adjusted H_s values based on the buoy data (regression equations shown above) were used. Figure 2.10, Figure 2.11 and Figure 2.12 show the results of comparison between the satellites. Figure 2.12 shows closer correlation than the other two comparisons. This is due to the fact that the TOPEX and ERS-1 missions largely overlapped. Young [37] concluded that the results from these cross validations indicate that for all practical purposes the three satellite missions have recorded the same global average wave conditions.

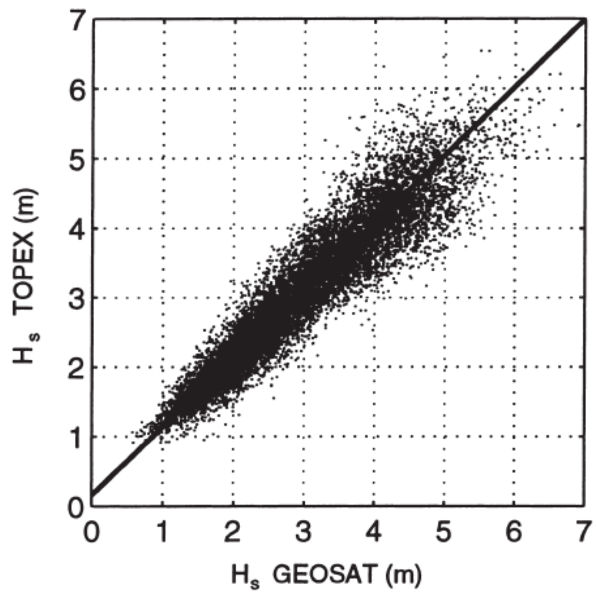

Figure 2.10: Global mean monthly values of corrected GEOSAT altimeter H_s compared with mean monthly values of corrected TOPEX altimeter H_s. The solid line is Equation (2.3-4) [37]

$$H_s(\mathrm{TOPEX}) = 0.978\ H_s(\mathrm{GEOSAT}) + 0.158 \tag{2.3-4}$$

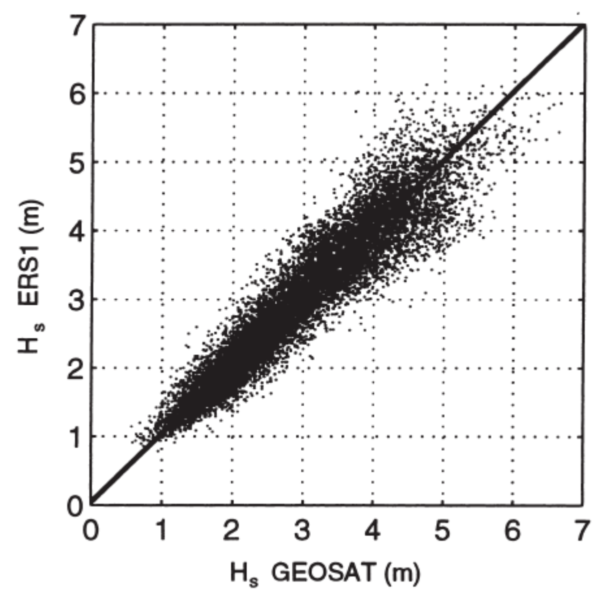

Figure 2.11: Global mean monthly values of corrected GEOSAT altimeter H_s compared with mean monthly values of corrected ERS1 altimeter H_s. The solid line is Equation (2.3-5). [37]

$$H_s(\mathrm{ERS1}) = 0.998\ H_s(\mathrm{GEOSAT}) + 0.046 \tag{2.3-5}$$

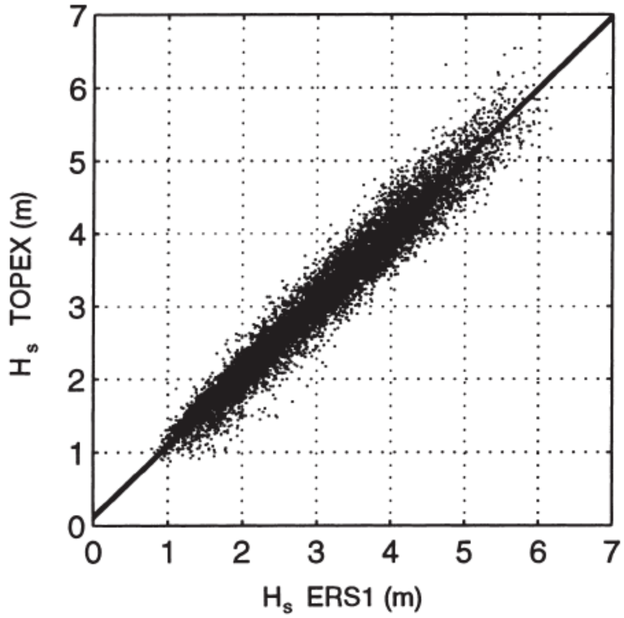

Figure 2.12: Global mean monthly values of corrected ERS1 altimeter H_s compared with mean monthly values of corrected TOPEX altimeter H_s. The solid line is Equation (2.3-6) [37]

$$H_s(TOPEX) = 0.980\ H_s(ERS1) + 0.112 \qquad (2.3\text{-}6)$$

2.4 Wave Period Data

Wave period data play an important role in spectral analysis. However, radar altimeter cannot measure the wave period whereas SAR can. But, the utility of SAR based wave period data is currently limited due to technical issues such as converting image spectrum to wave spectrum, which are still being studied. Therefore, in this thesis, the Young's [40] mean wave period data from the third generation spectral wave model (WAM) developed by Komen et al. [18] are used. This model has been adopted by the international community, and it has been validated numerous times [17]. Although both peak wave period, T_p and mean wave period, T_m are provided in the Young's data, only the T_m data based on the weighted mean frequency of the spectrum are used for the extreme wave prediction model in Section 3.2. T_p is a reliable measure of the longer period waves whereas T_m tends to reflect the locally generated wind sea, which is the focus of this thesis (Table 2-2) [40]. The T_m data are from the global implementation of the WAM model at the European Centre for Medium Range Weather Forecasting (ECMWF) covering a five year period from June 1992 to May 1996. This particular data

period was chosen by Young [40] to overlap some of the satellite radar altimeter data periods. The WAM results were distributed into 3^o x 3^o grids and had a time step of 12 hours. So, for the five year period, approximately 3600 observations were available. They were then ranked to calculate the probability of exceedence at each grid point. The methodology of calculating the probability of exceedence is further discussed in Section 3.1.1.

Table 2-2: Wave period definitions [35]

Symbol	Title	Description	Moment definition	Value (s)
T_E	Energy period	Total wave power in deep water $= \frac{\rho g^2}{4\pi} T_E m_0$	m_{-1}/m_0	12.51
T_1 or $\overline{T}$	Mean period	1/average frequency of the spectrum	m_0/m_1	11.27
T_2 or T_z	Zero-crossing period	The average period of the zero-upcross waves	m_2/m_0	10.38
T_I	Integral period	The T_z of the integral of the record.	m_{-2}/m_0	13.00
T_M or T_p	Modal period or peak period	The period at which $S(f)$ has its highest value	None	14.60
T_{pc}	Calculated peak period	Approximation to the modal period	$m_{-2}m_1/m_0^2$	15.00
T_c	Crest period	The average period between wave crests	m_2/m_4	0.00

Since the wave period data used in this thesis are based on numerical modeling, their limitations must be understood [35]. Limited information is available regarding the errors in wave period measurement, but some studies regarding the global WAM model as used at the ECMWF have been carried out by Janssen et al. [17]. Simply put, T_p is an inherently unstable parameter, and Tucker [35] recommends using zero-crossing period, T_z or mean period T_m that depend on the entire spectrum. This is another reason why only T_m is used in this thesis.

3 Most Probable Extreme Wave Height

In this section, prediction of the most probable extreme wave heights based on short term order statistics is discussed. The short term order statistics requires spectral analysis based on extreme significant wave heights and extreme mean wave periods. The extreme significant wave height data from Alves and Young [1] is discussed in Section 3.1, and prediction of corresponding extreme wave period data is discussed in Section 3.2.

Extreme waves with the return periods of 50 and 100 years are also known as design waves as they are used to determine the operational threshold of a design of marine structure or vessel. Until recently, these waves were predicted based on in-situ measurements that often provided localized extreme wave data with limited data resolution. The statistical analyses that followed were sophisticated enough, but there were only as good as the data that were used for the analyses. It was not until the remote sensing data from satellites became available when global prediction of extreme significant wave heights was possible.

The simplest approximation to ocean wave statistics is built on the premise that sea surface elevation and related fluid motions can be approximated by a large number of independent sinusoids leading to a Gaussian random process based on the central limit theorem [28]. Although this is only an approximation, with correct assumption and right application, this approach can provide a powerful tool to observe otherwise complex ocean environment in a much simplified way.

In this thesis, short term order statistics is used as one approach in developing an extreme wave prediction model. In doing so, the following assumptions have been made; the random processes associated with extreme wave events are stationary and ergodic. These assumptions are valid for "short" time intervals that can range from hours to a few days while a storm maintains its characteristics [34].

The most probable extreme wave prediction model is based on extreme significant wave heights, extreme $H_{s,}$ that are estimated by Alves and Young [1] from the satellite radar altimeter data. Assuming that the extreme H_s data corresponds to a storm with the most probable extreme wave height, it can then be used to construct a storm

spectrum. In choosing a spectrum to represent extreme sea conditions, two parameter spectra are used: the Bretschneider and Ochi's hurricane-generated sea spectra. Although it is possible to use a one parameter spectrum such as the Pierson-Moskowitz spectrum that requires only one parameter input, these two parameter spectra can more accurately describe extreme sea conditions and are frequently used for extreme sea conditions. Nevertheless, the Pierson-Moskowitz spectrum is used for wave simulation runs to validate these two parameter spectra as discussed in Section 3.4. The Bretschneider and Ochi's hurricane-generated sea spectra require significant wave height and mean wave period inputs, and the methodology of estimating extreme mean period, extreme T_m associated with extreme H_s is discussed in Section 3.2.

Storm statistics

For each storm, a spectrum can be constructed using significant wave height and average wave period (if known) and short term order statistics can be calculated. Once calculated, probability of non-exceedence is used to define a design wave height or other extreme parameters since the actual wave height that would cause a structural failure can deviate from the RMS value depending on resonance and other factors [35]. The application of order statistics is discussed in detail by Ochi [31], and it is used to estimate the most probable extreme wave heights given the extreme significant wave heights with the return periods of 50 and 100 years.

Wave Simulation

As a way to validate and compare the results from order statistics applied to a spectral analysis, a wave simulation using the Pierson-Moskowitz spectrum is used. It corresponds to the Bretschneider spectrum when the waves are fully developed. The Pierson-Moskowitz spectrum is a one parameter spectrum, and it can be easily constructed based only on significant wave height data. This eliminates the need for a second parameter input (i.e. wave period), and the wave simulation can provide a quick and relatively accurate way of validating the most probable extreme wave prediction model based on spectral analysis. This is further discussed in Section 3.4.

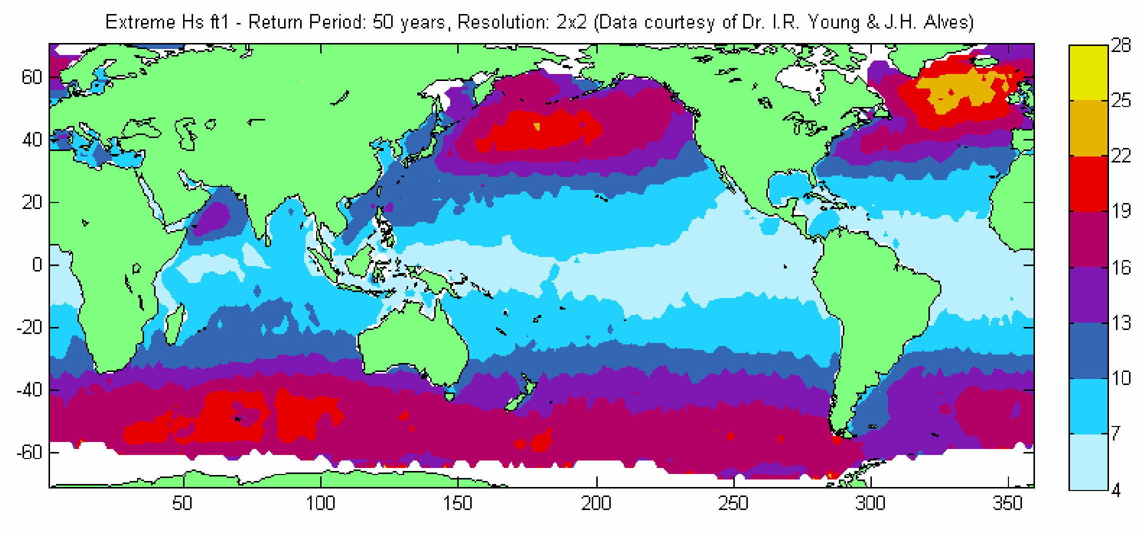

Figure 3.1: Significant wave height, 50 yr return period, FT1/IDM data [2]

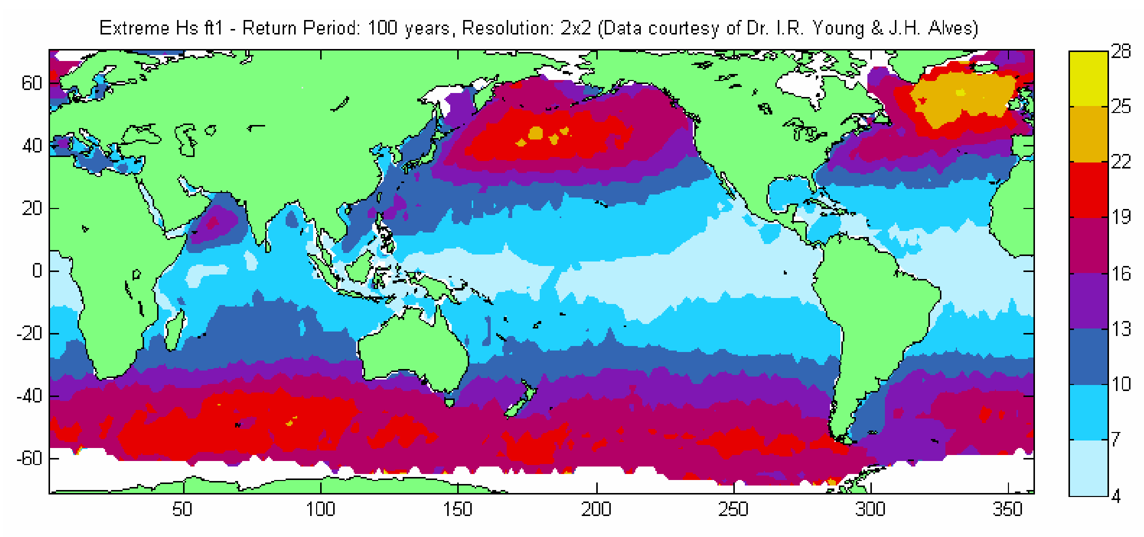

Figure 3.2: Significant wave height, 100 yr return period, FT1/IDM data [2]

Location Selection

Alves and Young's [1] ocean data cover the entire globe, and the most probable extreme wave prediction model discussed in this thesis can be applied to any geographical location with reliable data. For this thesis, however, two areas with the most dynamic ocean environments have been chosen: the North Pacific (21^{o} N - 45^{o} N & 161^{o} E -149^{o} W) and the North Atlantic (37^{o} N – 57^{o} N & 49^{o} W – 19^{o} W). Although the

Southern Ocean is known to possess the roughest body of water, these two other areas are more frequently traveled and explored and therefore, a detailed study of ocean wave statistics is certainly warranted in these areas. Figure 3.1 and Figure 3.2 show the violent waters of the North Pacific and the North Atlantic as shown by the predicted extreme H_s from the Atlas of the Oceans [2].

3.1 Extreme H_s prediction (Alves and Young)

The extreme significant height, extreme H_s, prediction model by Alves and Young [1] [2] is based on the satellite radar altimeter data, and more detailed description of their work can be found in [1]. Alves and Young [1] used the satellite data that spanned a ten year period from 1986 to 1995 that included GEOSAT, TOPEX/Poseidon and ERS-1. These missions yielded approximately 78 months or 6.5 years of effective observation data as discussed in Section 2.1. The satellite radar altimeter data were allocated into 2^o x 2^o (latitude x longitude) and 4^o x 4^o grid elements for further analyses.

Grid sizes were chosen for space-time resolution as well as statistical reliability. Cooper and Forristall [12] showed that the area with a radius ranging from 100 km to 300 km (roughly corresponding to 2^o x 2^o to 4^o x 4^o grid size) is close to optimal based on data resolution. According to their research, satellite measurements showed good agreements with in-situ measured data for the equivalent size of area. Based on the findings from Cooper and Forristall [12], Alves and Young [1] chose 2^o x 2^o and 4^o x 4^o grid sizes for their extreme H_s prediction model. Still, there is an issue of isolating the effects of more than one local storm system, and this is discussed in Section 5.1.4.

N-year extreme wave height is defined as the wave height that is exceeded on average once every N year(s) on average. In this thesis, the 50 and 100 year return periods are considered as they are typically used as standards. The following methodology was used by Alves and Young [1] to estimate extreme H_s.

<u>Extreme H_s prediction methodology</u>

1. Time history of wave heights or H_s maxima from satellite measurements was collected.

2. The series of maxima were ranked by their magnitude.
3. Cumulative distribution functions (CDFs) were assigned to each maxima based on the ranking.
4. Statistical distribution models (Fisher-Tippett Type 1 or Weibull or similar types) were fitted to the CDFs.
5. Goodness of fit tests was assessed.
6. Based on the statistical distribution model, the data were extrapolated beyond the data period to a probability level of interest that corresponds to an extreme event return period of N years (typically, N = 50 or 100)

3.1.1 Wave Height Database Construction

In addition to using good quality data, the choice of statistical distribution model and the construction of cumulative distribution functions (CDFs) impact the accuracy of a prediction model. The following section summarizes the construction technique and distribution models used by Young and Holland [38] and Alves and Young [1].

CDF

Cumulative distribution function is constructed using the ranking of maxima. First, each value of H_s is ranked within each grid. Either the mean value of each satellite pass or the maximum value of the pass at each grid square can be selected, and Young and Holland [38] chose the maxima approach for their model. Then using Equation (3.1-1), the probability of exceedence is calculated where m is equal to a rank based on order of magnitude and N equals the total number of passes or data points within the grid square [38]. Once the probability function is constructed as shown in Figure 3.3, a statistical distribution model can be fitted next.

$$\mathrm{Pr} = \frac{m}{N+1} \tag{3.1-1}$$

Where:

m = a rank based on descending order of magnitude

N = the total number of passes or data points within the grid square

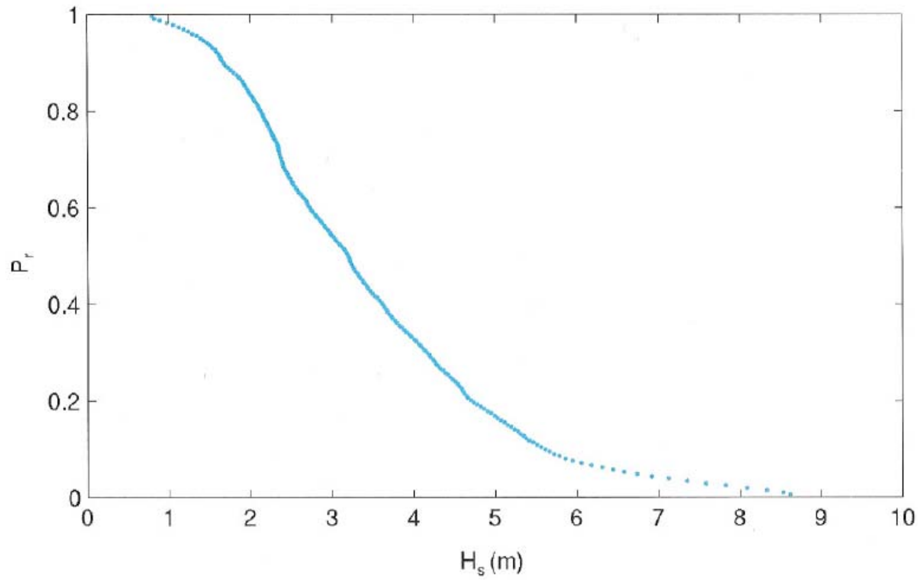

Figure 3.3: An example of the probability distribution function (i.e. probability of exceedence, P_r as a function of the significant wave height, H_s). The example shown is from the north-eastern Atlantic ocean (54^o N, 346^o E) [38]

IDM vs. POT

The selection of statistical distribution model depends on how these maxima values are organized, and Alves and Young [1] included the initial distribution method (IDM) and the peaks over threshold (POT) methods for CDF. Using IDM, all available measurements are ranked based on wave heights regardless of their association to storm events, and this could result in the data base containing multiple values from a single storm event. Consequently, there is a possibility that a statistical distribution model used to fit the data may not accurately describe the wave height distribution within a given grid square due to repeated wave height data. However, the observations in the North Sea have shown that IDM can indeed be effectively used to estimate extreme significant wave heights [7], and the IDM method has been validated. The POT method is recommended by the International Association for Hydraulic Research (IAHR) to be used in estimating extreme H_s. Based on this method, a series of wave heights that exceed a given threshold are used only to fit the curve. Although this method is widely used, it

also has some shortcomings. The main one is that it disregards the possibility of the highest wave coming from the second largest storm (i.e. from the values below the chosen threshold) [35]. This is further discussed in Section 5.1.4.

3.1.2 Statistical Distribution Models: Fisher-Tippett Type 1 & Weibull 3-parameter

Alves and Young [1] used two popular distribution models for extreme significant wave height prediction, and they were Fisher-Tippett Type 1 (Equation 3.1-2) based on IDM and Weibull 3-parameter (Equation 3.1-3) based on POT. The extreme H_s extrapolation based on these distribution models is discussed next.

The Fisher-Tippett type 1 (FT1) distribution

$$F(x) = \exp\left[-\exp\left(-\frac{x-\alpha}{\beta}\right)\right] \qquad (3.1\text{-}2)$$

Where:

x = significant wave height (independent variable),
α = location parameter
β = scale parameter

The Weibull 3-parameter (W3P) distribution

$$\begin{aligned} &F(x) = 0 \quad if \;\; x < \theta \\ &F(x) = 1 - \exp\left[-\left(-\frac{x-\alpha}{\beta}\right)^{\theta}\right] \quad if \;\; x > \theta \end{aligned} \qquad (3.1\text{-}3)$$

Where:

x = significant wave height (independent variable)
β = scale parameter
θ = shape parameter
α = location parameter

3.1.3 Extreme H_s Extrapolation

The extreme H_s prediction is done by extrapolating the wave height data using the statistical distribution models. Assuming a wave height data set follows the FT1 distribution, an extrapolation plot can be constructed by linearizing Equation (3.1-2) as in Equation (3.1-4), and Equation (3.1-5) is the linearized equation for W3P. These plots of linearized equations are shown in Figure 3.4 and Figure 3.5. Figure 3.4 shows the two fitting lines: one based on the entire data set and one based on the top six data points. Based on these figures, the W3P distribution seems to represent the overall wave height data set better than FT1, but Tucker and Pitt [35] point out that over the longer period of data, FT1 seems to actually work better than W3P.

$$-\log\left[-\log F(x)\right] = \frac{x-\alpha}{\beta} \qquad (3.1\text{-}4)$$

$$\log\left\{-\log\left[1-F(x)\right]\right\} = \theta\left[\left(\log\left(x-\alpha\right)\right) - \log\beta\right] \qquad (3.1\text{-}5)$$

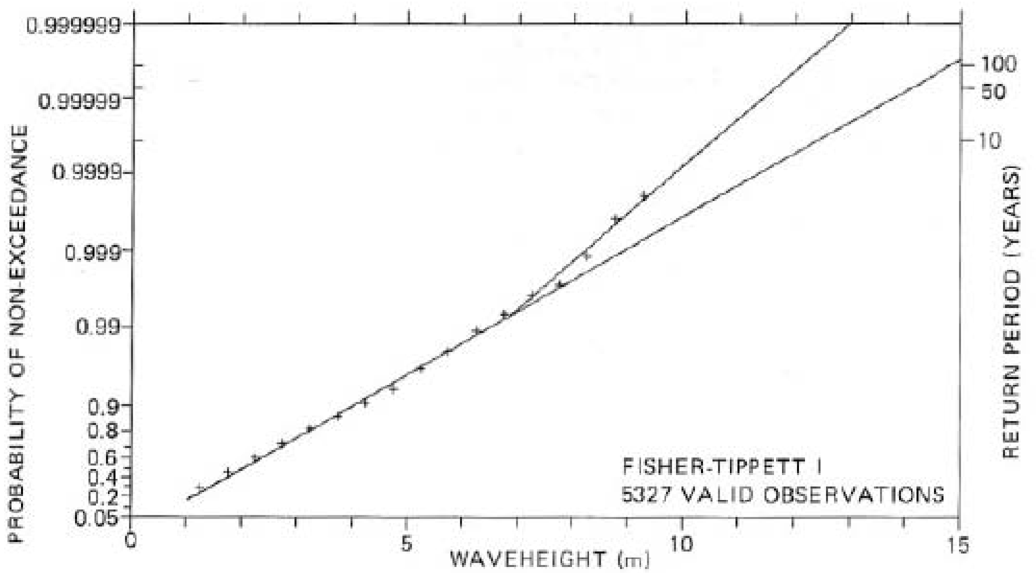

Figure 5.12 – The probability of the significant waveheight not exceeding H_{m0} plotted against H_{m0} on scales which would give straight line if the data came from an FT-1 distribution. The two lines shown were fitted by eye respectively to the bulk of the data and to the top six points only. The data are the same as used for Fig 5.11. (From Fortnum, 1981a)

Figure 3.4: The probability of exceedence extrapolation using a Fisher-Tippett-1 distribution [35]

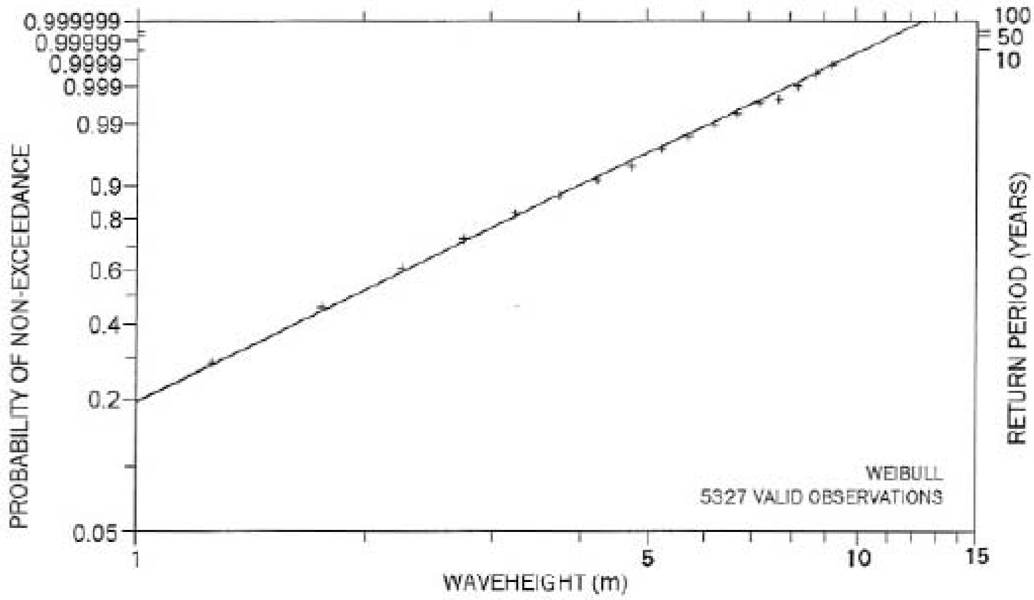

Figure 3.5: As Figure 2 except that 3-parameter Weibull probability scales are used with theta = 0.15m [35]

In Figure 3.6, the estimated extreme H_s based on the FT1/IDM combination and the W3P/POT are compared, and these plots are generated using the parameter values given in [2]. Figure 3.6 shows the extreme H_s prediction for the 2^o x 2^o grid size and the 50 year return period at 43^o N and 163^o E. This particular location is randomly chosen for a detailed analysis that follows. The top two figures show the line fitting technique as discussed in Section 3.1.2. Since FT1 is used to fit the entire data set, it shows a good fitting to the underlying data set whereas for W3P, it shows partial agreement since only a part of data set exceeding a certain threshold is used. Based on a private conversation with Young, it is found that the FT1 fitting by Alves and Young [2] was not actually based on this particular CDF as shown in Figure 3.6 but rather the original wave height data that were used to construct this CDF. This difference is represented in Figure 3.7, which shows the difference between the CDF (FT1 REFIT) and the fitting curve (FT1) based on the actual wave height maxima. Also, it can be seen that extreme H_s (20.75 m) predicted by fitting the actual CDF slightly differs from the value estimated (20.05 m) by Alves and Young [2]. Nevertheless, it is encouraging to note that the two totally different techniques arrived at the very similar results, and this further validates the extrapolation technique described in Section 3.1.1. Since the data from Alves and Young [2] have been validated, and because the difference is minimal, their data are used for the remainder of

this study. The bottom four plots in Figure 3.6 show linearization of distribution functions and finding an extreme value corresponding to a given probability of non-exceedence, and it is discussed next.

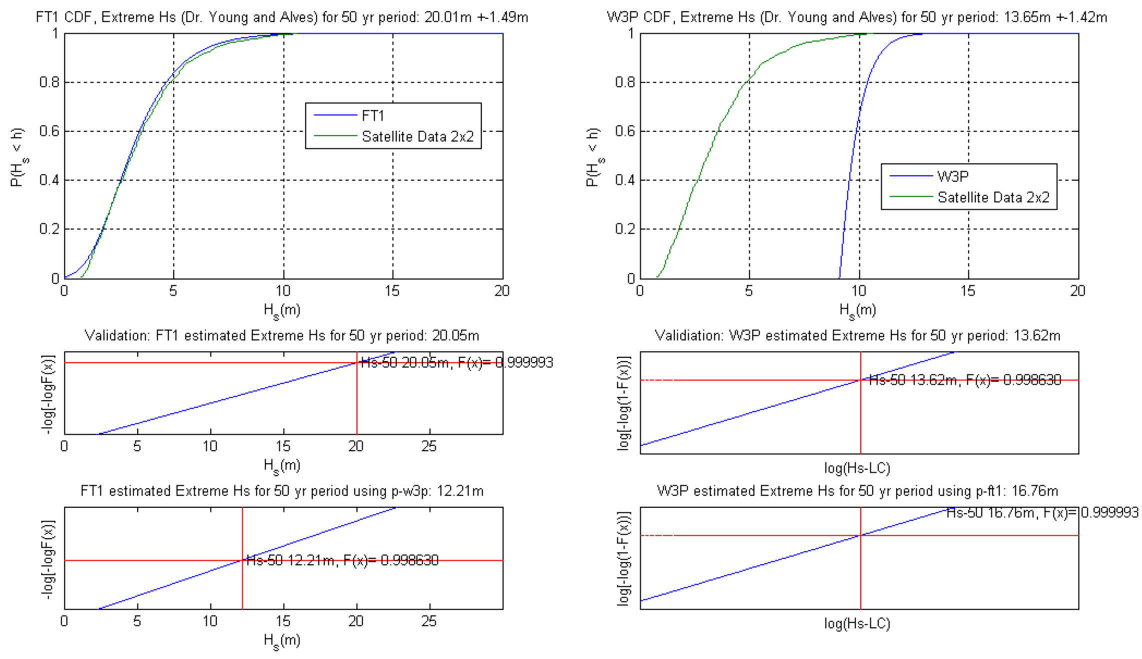

Figure 3.6: H_s prediction comparison, 2 deg x 2 deg grid size, 50 yr return period (43° N, 163° E)

An extreme H_s value for a given H_s at a geographical location is found at the intersection of linearized distribution curve and corresponding probability level. In the bottom four plots of Figure 3.6, the probability of non-exceedence, F(x), is plotted on the y-axis, and H_s is plotted on the x-axis (not explicitly for W3P). The bottom four plots of Figure 3.6 are generated using the linearized FT1 and W3P distribution curves with the parameters given by Alves and Young [2]. The extreme H_s estimates in the middle two plots (Figure 3.8) are slightly different from the values calculated by Alves and Young [2] as shown in the top two plots, although they are supposed to be equal. However, the cause of this difference is not further investigated since these plots are generated only to validate the extrapolation technique used by Alves and Young [2], and the values are indeed very close to each other.

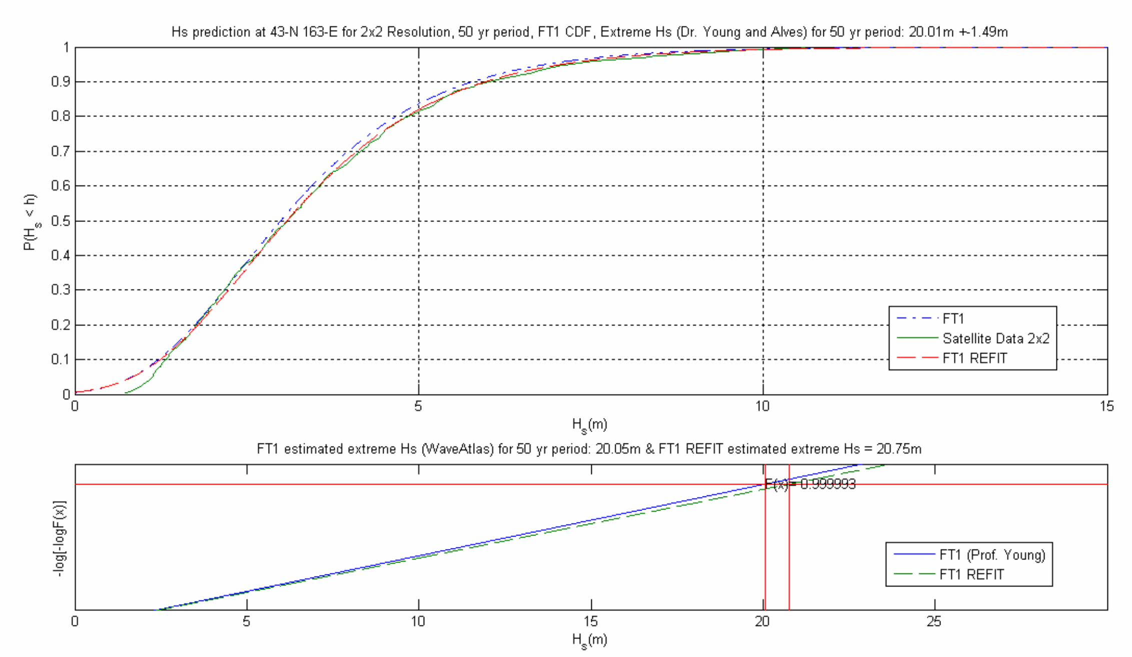

Figure 3.7: Extreme H_s prediction using FT1, 2 deg x 2 deg grid size for 50 yr return period (43° N, 163° E)

The following analysis considers the effect of probability of non-exceedence as shown in the bottom four plots of Figure 3.6, and they are shown separately in Figure 3.8 and Figure 3.9. In Figure 3.9, the linearized FT1 curve is used with the POT probability of non-exceedence, and the linearized W3P curve is plotted with the probability of non-exceedence based on IDM. The probabilities of non-exceedence based on IDM and POT are given in Equation (3.1-6) and Equation (3.1-7), respectively. The equations presented here are for the 100 year return period, but the same equations can be used for H_s50 with proper substitutions.

$$P(Hs < Hs100) = 1 - \frac{D}{T_{100}} \tag{3.1-6}$$

$$P(Hs < Hs100) = 1 - \frac{N_Y}{(100 N_{POT})} \tag{3.1-7}$$

Where:

H_s100 = extreme significant wave height with the 100 year return period

D = a decorrelation time scale in hours for observations of H_s

T_{100} = the number of hours in 100 years

D = 3 hours

T_{100} = 877777.78 hours, which includes leap years were used for the following analyses.

N_{POT} = the number of selected POT points

N_Y = the number of years covered by POT (50 or 100)

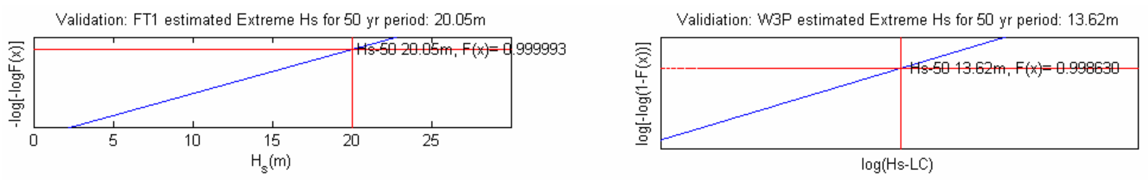

Figure 3.8: FT1/IDM vs. W3P/POT (43° N, 163° E)

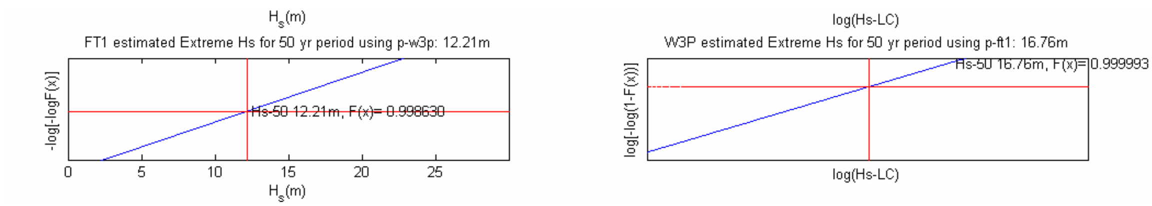

Figure 3.9: Probabilities of non-exceedence comparison (FT1/POT vs. W3P/IDM) (43° N, 163° E)

The bottom four plots of Figure 3.6 show interesting comparisons based on using two different probabilities of non-exceedence: IDM and POT. Figure 3.8 shows that the estimated extreme H_s using the FT1/IDM combination is much greater than that of the W3P/POT. Mainly, this is because the probability of non-exceedence is higher using the IDM method (Equation 3.1-6) than the POT method (Equation 3.1-7). The effect of probability of non-exceedence on a prediction model is shown in Figure 3.9 where the FT1 distribution is plotted with the probability of non-exceedence based on POT, and the W3P distribution is plotted with the probability level based on IDM. In this case, the W3P/IDM combination actually yields a higher estimated extreme H_s than the FT1/POT combination. Alves and Young [1] discuss the differences between two models in [1], and it is also summarized in Section 3.1.5. Lastly, Figure 3.10 shows similar results for the 4^o x 4^o grid size for the same location as Figure 3.6. It can be seen that the extreme H_s values for the 4^o x 4^o grid elements are less than that of the 2^o x 2^o grid elements, and this is also discussed in Section 3.1.5.

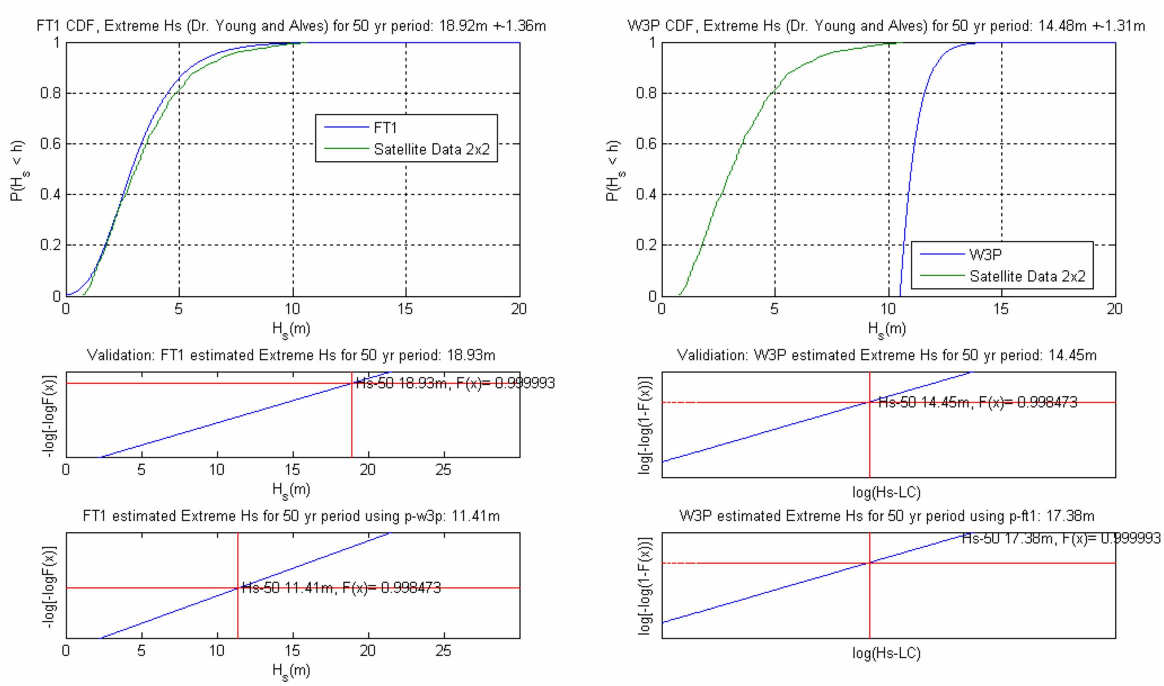

Figure 3.10: H_s prediction comparison, 4 deg x 4 deg grid size, 50 yr return period (43^o N, 163^o E)

3.1.4 Validation

Alves and Young [1] used the following goodness of fit tests on the satellite based estimates and co-located buoy data to validate the extreme H_s data: the Cramer Von Mises test, a modified Kolmogorov-Smirnov test, and a criterion based on the correlation coefficient proposed by Goda and Kobune. Their tests yielded acceptable results for the both approaches although the W3P/POT scored better than the FT1/IDM method. Also, the data based on 2^o x 2^o grid size scored higher than 4^o x 4^o grid size. These results are further discussed in Section 3.1.5. Perhaps the most important finding from the goodness of fit tests was that the differences between the buoy-derived extreme H_s with the return period of 100 years and the H_s100 based on IDM and POT differed by less than 10% (under 5% for all but one case). This suggests that the shorter period altimeter database can indeed provide consistent extreme significant wave height estimates [1].

3.1.5 Data Comparison (FT1/IDM vs. W3P/POT & 2^o x 2^o vs. 4^o x 4^o)

Alves and Young [1] have shown the validity of satellite radar altimeter data in predicting extreme significant wave heights and support the previous studies done by

Cooper and Forristall [12]. Cooper and Forristall [12] have found that 100-year extreme wave heights, H_s100, can be estimated based on the satellite data base employing the same CDF techniques used for the buoy data. For the goodness of fit tests, the W3P/POT methodology scored better than the FT1/IDM. However, Alves and Young [1] point out that because POT disregards some of data points based on the threshold value, it under-samples storm peaks, and this leads to underestimation of H_s100. Also, it should be noted that finding the threshold value itself poses a problem because this depends on extensive storm data at a given point, and this type of data is currently almost non-existent. Therefore, Cooper and Forristall [12] as well as Alves and Young [1] conclude that the POT approach is less desirable for calculating long-term extreme significant wave heights than the IDM method. Alves and Young [1] also suggest that until a database with high temporal and spatial resolution becomes available the best current approach for estimating long-term extreme environmental values with acceptable accuracy and statistical reliability is to use the IDM based data. Lastly, wave height data based on 2^o x 2^o grid elements gives more acceptable results than those of 4^o x 4^o. This is due to the fact that the 4^o x 4^o grid elements are more likely to include environmental data resulting from different climatology than the local one (i.e. more than one local storm system). The data based on multiple environmental effects would make isolating those effects of a local storm system a challenge and therefore, they are less ideal for this application.

Based on these findings from Alves and Young [1], only the extreme H_s data based on the FT1/IDM method is used for constructing a global data base of the most probable extreme wave height data base for the North Pacific and the North Atlantic. Both 2^o x 2^o and 4^o x 4^o grid sizes are included in this study for comparison purposes.

3.2 Extreme T_m Prediction

A key building block of ocean wave statistics is spectral analysis. For this study, the Bretschneider spectrum, which is the modified Pierson-Moskowitz spectrum, and the Ochi's hurricane-generated sea spectrum are selected to represent storm or extreme seas. These are two parameter spectra that require significant wave height and wave period data. The main advantage of spectral analysis is that constructing a spectrum for a given

extreme sea state allows many subsequent statistical analyses that would otherwise not be available solely based on extreme significant wave height data. Furthermore, until SAR data can provide individual trough and crest data, no other remote measurement methods currently exist that are better than simulations based spectral analysis that also includes wave period data. In Section 2.4, it has been shown that predicting wave period is not so straightforward. Nevertheless, the same technique that was used to extrapolate the extreme significant wave heights (Section 3.1) can be used to estimate the corresponding extreme mean wave periods, extreme T_m, and this will allow spectral analysis regarding extreme waves. And, such a possibility can only be beneficial to any future studies involving extreme and rare waves. In Section 3.2.1, the T_m extrapolation technique using the T_m data from Alves and Young [2] is discussed, and the results are compared to the other known wave period prediction methods based on extreme H_s in Section 3.2.2.

3.2.1 Methodology

In predicting extreme T_m, the exact same procedure used for the extreme H_s extrapolation in Section 3.1 is used. Mean wave period, T_m, is defined as 1/average frequency of the spectrum. In terms of spectral moments, it can be shown as Equation (3.2-1) with each spectral moment defined in Equation (3.2-2).

$$T_m = m_0/m_1 \tag{3.2-1}$$

$$m_n = \int_0^\infty f^n S(f)\,df \tag{3.2-2}$$

<u>The Weibull 2-parameter (W2P) distribution</u>

$$\begin{aligned} F(x) &= 0 \quad if \;\; x < 0 \\ F(x) &= 1 - \exp\left[-\left(\frac{x}{\beta}\right)^{\theta}\right] \quad if \;\; x > 0 \end{aligned} \tag{3.2-3}$$

Where:

x = mean wave period (independent variable)

β = scale parameter

θ = shape parameter

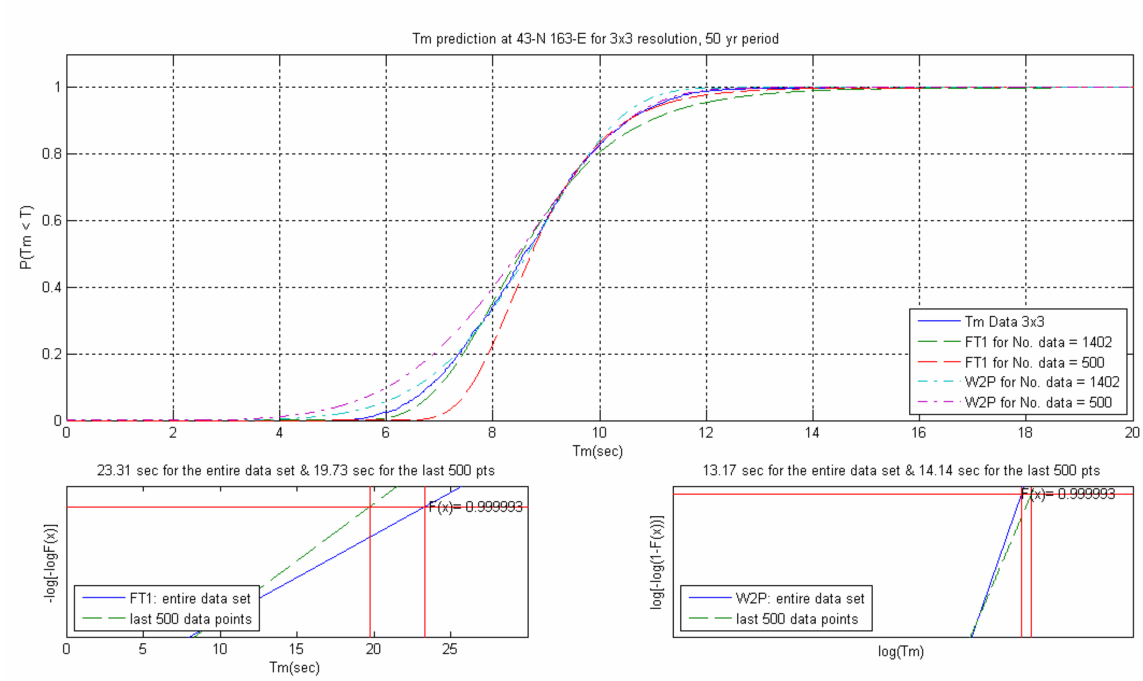

Figure 3.11: Extreme T_m prediction, 3 deg x 3 deg resolution for 50 yr return period (43^o N, 163^o E)

Each T_m data element (Section 2.4) from Alves and Young [2] and Young [40] corresponds to a 3^o x 3^o grid element containing 1402 points. The grid size of 3^o x 3^o is based on the global WAM model (Section 2.4), and it differs from the grid sizes used by Alves and Young [2]. The Fisher-Tippet Type 1, FT1 (Equation 3.1-2) and the Weibull 2-parameter, W2P (Equation 3.2-3) distribution functions are fitted to the entire 1402 data points and as well as the last 500 data points that corresponded to the tail end of CDF. As shown in Figure 3.11, both the FT1 and W2P distribution models do not exactly fit the entire data set. In the case of W2P, this observation confirms the known fact that a 2-parameter Weibull distribution usually cannot be made to fit both the higher and lower ranges of the data [35]. A few other distribution functions were also considered, but none yielded acceptable results, and therefore, they are not mentioned. Furthermore, neither the Weibull 3-parameter nor the Fisher-Tippett Type III distribution model is used since the actual T_m values (in order to construct a CDF) were not available for this study, and therefore, no determination could be made about the threshold values needed for the above two distribution functions as discussed in Section 3.1.1. Then, as a compromise, fitting the last 500 data points seems to offer a partial solution since the extrapolation would take a place beyond the tail end of CDF. After all, the extreme statistical analysis revolves around how accurate one can model the tail end of a CDF,

and this further validates the approach. The results from the line fitting are shown in Figure 3.11. The line fitting and goodness of fit tests are done using the Matlab's "fit" function [25].

The extreme T_m extrapolation results in Figure 3.11 show that both FT1 and W2P yield good fittings for the last 500 data points, but closer observation indicates that W2P may be a better fit than FT1. The bottom two plots of Figure 3.11 show extreme T_m values based on the two distribution functions. It can be seen that the extreme T_m values based on W2P (the plot on the right) is substantially less than that of FT1 (the plot on the left) for the last 500 data points. Also, W2P provides a narrower range of T_m values based on the entire set and the last 500 data points than FT1. This suggests that W2P may be a better fit than FT1, and this is confirmed in the following goodness of fit tests.

Goodness of Fit Tests

Total of five criteria are used to perform the goodness of fit tests, which are part of the Matlab's "fit" function [25]: sum of squares due to error, coefficient of determination, degrees of freedom, degree-of-freedom adjusted coefficient of determination, and root mean squared error (standard error). The following is a brief description of these criteria from the Matlab help file [25].

Sum of squares due to error (sse) is the total deviation of the data values from the fit to the data values.

$$SSE = \sum_{i=1}^{n} w_i (y_i - \hat{y}_i)^2 \qquad (3.2\text{-}4)$$

A value closer to 0 indicates that the model has a smaller random error, and the fit will be more suitable for prediction.

The coefficient of determination (rsquare) is the measurement of how successful the fit explains the variation of the data, and it is defined with the total sum of squares.

$$\begin{aligned} SST &= \sum_{i=1}^{n} w_i (y_i - \bar{y})^2 \\ R\_square &= 1 - \frac{SSE}{SST} \end{aligned} \qquad (3.2\text{-}5)$$

R-square can take on a value between 0 and 1, the closer the value is to 1, the greater portion of variance is accounted for by the distribution function. For example, the value of rsquare for FT1 with 1402 data points is 0.9937. This indicates that the fit explains 99.37% of the total variation in the data about the average.

Degrees of freedom (dfe) use the R-square statistic and adjust it based on the residual degrees of freedom.

$$v = n\text{-}m \tag{3.2-6}$$

where n = the number of base data values and m = the number of fitted coefficients (2 for both FT1 and W2P). The v indicates the number of independent pieces of information pertaining to the n data points, which are used to calculate the sum of squares.

Degree-of-freedom adjusted coefficient of determination (adjrsquare) is defined in Equation (3.2-7):

$$adjrsquare = 1 - \frac{SSE(n-1)}{SST(v)} \tag{3.2-7}$$

The adjrsquare can take on any value less than or equal to 1. The closer the value is to 1, the better the fit is. For this particular analysis, rsquare is equal to adjrsquare.

Root mean squared error (RMSE) is also known as the fit standard error and the standard error of the regression. It is an estimate of the standard deviation of the random component in the data.

$$RMSE = \sqrt{\frac{SSE}{v}} \tag{3.2-8}$$

As with SSE, a value closer to 0 indicates that the model has a smaller random error, and the fit will be more suitable for prediction.

The results of goodness of fit tests are summarized in Table 3-1 for the extreme T_m data from 43-N 163-E. Although both FT1 and W2P distribution functions show good agreement with the last 500 data points as shown in their rsquare values (the closer to 1, the better the fit), W2P is a slightly better fit than FT1 based on the sse and rmse values, which measure small random errors. In this case, W2P has a smaller random error than FT1. The subsequent analyses include extreme T_m values based on the both distribution models for comparison purposes.

Table 3-1: Goodness of fit results (43^o N, 163^o E)

Distribution	FT1	FT1	W2P	W2P
Data points	1402	500	1402	500
Distribution model	F(x) = exp{-exp[(lc-x)/sc]}	F(x) = exp{-exp[(lc-x)/sc]}	F(x) = 1-exp[-(x/sc)^sh]	F(x) = 1-exp[-(x/sc)^sh]
Coefficients (with 95% confidence bounds)	lc = 8.046 (8.039, 8.052) sc = 1.283 (1.274, 1.292)	lc = 8.37 (8.363, 8.378) sc = 0.9555 (0.9497, 0.9612)	sc = 9.128 (9.124, 9.133) sh = 6.758 (6.725, 6.792)	sc = 9.037 (9.033, 9.042) sh = 5.53 (5.499, 5.561)
sse	0.7327	0.0124	0.3642	0.0119
rsquare	0.9937	0.9977	0.9969	0.9978
dfe	1400	498	1400	498
adjrsquare	0.9937	0.9977	0.9969	0.9978
rmse	0.0229	0.0050	0.0161	0.0049

3.2.2 Comparison to a Practical Calculation

The aforementioned extreme T_m extrapolation technique has a limitation as it does not apply a distribution model that can be fitted to the entire data set. However, when compared to a practical calculation technique available in the literature, the results are not too far off. Tucker and Pitt [35] offer a practical method of calculating zero-crossing period, T_z, associated with an extreme wave height. Although it is a rather simple way of estimating the T_z value, the method provides a quick way of comparing the values from the extrapolation and validating them to a certain extent. The following discussion focuses on the extreme wave zero-crossing period with the 50 year return period, T_{z50}.

The method described by Tucker and Pitt [35] calculates T_{z50} based on H_{s50}, significant wave height with the 50 year return period. For the comparison, the H_{s50} values from Alves and Young [2] are used. Assuming that it is deep water with unlimited fetch, a storm is assumed to have a significant steepness of 1/18 [35].

$$S_{s50} = \frac{2\pi H_{s50}}{g(T_{z50})^2} = \frac{1}{18} \tag{3.2-9}$$

Then solving for H_{s50} in meters (g = gravitational constant, 9.81 m/sec^2)

$$T_{z50} = 3.4\sqrt{H_{s50}} \tag{3.2-10}$$

This is the average zero-crossing period, but the following range is used instead since the measured period of the highest individual wave in a storm has a wide range of period values relative to T_z [6]. The range is given as:

$$1.05\ T_{z50} < T_{design\_wave} < 1.4\ T_{z50} \qquad (3.2\text{-}11)$$

The T_{design_wave} is the period associated with the design wave or extreme wave. For the 50 year return period, the aforementioned extrapolation technique estimates the mean wave period, T_{m50}. The corresponding T_{z50} using the Tucker and Pitt [35] method can be then calculated using the following relationship.

$$T_m = 1.087{*}T_z \qquad (3.2\text{-}12)$$

Although not too far off, there is a noticeable difference between the T_m values from the extrapolation and the method described by Tucker and Pitt [35], and this is summarized in Table 3-2. Using the H_{s50} value of 20.01 m from Figure 3.7, T_{z50} is equal to 15.21 seconds based on Equation (3.2-10). The corresponding T_{m50} using Equation (3.2-12) is 16.53 seconds, and this is larger than 14.14 sec from Figure 3.11. The difference is even greater when T_{design_wave} is considered. It can be seen that the practical calculation value falls between the values calculated by the FT1 (19.73 sec) and W2P (14.14 sec) distribution models using the last 500 data points as seen in Figure 3.11. Also included in Table 3-2 is the predicted extreme T_m value from wave simulation runs (Section 3.4) at the same location using the Pierson-Moskowitz spectrum. Its value of 16.96 seconds is closer to 16.53 seconds calculated using the Tucker and Pitt [35] method than the T_m value from the extrapolation. Interestingly, the simulation value is almost equal to the average of these two values, and this suggests that the actual prediction curve lies somewhere between the FT1 and W2P linefit curves. Furthermore, the simulation results falls almost at the middle of the design wave range suggested by Tucker and Pitt [35].

From Figure 3.11, it is clear that the FT1 and W2P distribution models are not optimal solutions for the entire data set. It is possible that the wave period distribution may not follow an existing distribution function, and a new distribution model may be required in order to fit the entire data set. However, it is shown in Section 3.3 that the T_m extrapolation based on the last 500 data points together with the extreme H_s can predict the most probable extreme wave heights that are quite comparable to the other prediction

methods. Furthermore, the average value of predicted extreme T_m values of FT1 and W2P seems too close to the value based on the wave simulation and T_{design_wave} to be regarded as just a mere coincidence as shown in Table 3-2. Then not so surprisingly, the predicted most probable extreme wave heights using the average values from FT1 and W2P are even closer to the values predicted by other prediction formulas and the wave simulation than the ones based on individual distribution functions of FT1 and W2P. This is further discussed in Section 3.3.

Table 3-2: T_m prediction results comparison, 3 deg x 3 deg grid size (43° N, 163° E)

	T_m (sec)
FT1, 1402 data pts, 50 yr period	23.31
FT1, 500 data pts, 50 yr period	19.73
W2P, 1402 data pts, 50 yr period	13.17
W2P, 500 data pts, 50 yr period	**14.14**
Average FT1 & W2P (500 pts)	**16.94**
Tucker and Pitt (for 50 yr period only)	**16.53**
Tucker and Pitt (design wave range)	**15.97 – 21.29**
Wave simulation, 50 yr period	**16.96**
FT1, 1402 data pts, 100 yr period	24.19
FT1, 500 data pts, 100 yr period	20.40
W2P, 1402 data pts, 100 yr period	13.28
W2P, 500 data pts, 100 yr period	**14.29**
Average FT1 & W2P (500 pts)	**17.35**
Wave simulation, 100 yr period	**17.34**

3.3 Most Probable Extreme Wave Height Prediction

The most probable extreme wave heights, extreme $H_{prob,}$ that correspond to extreme significant wave heights can be predicted using Ochi's short term order statistics [31]. The two spectra considered for storm sea conditions are two parameter spectra that require extreme significant wave height (Section 3.1) and corresponding wave period data (Section 3.2). Equation (3.3-1) and Equation (3.3-3) show the Bretschneider spectrum and the Ochi's hurricane-generated sea spectrum [30], which is a modified JONSWAP spectrum. Both spectra are widely used for storm sea conditions and give similar results even though there are some noticeable differences. These differences are further discussed in the following sections.

Bretschneider spectrum (the modified Pierson-Moskowitz spectrum)

$$S(f) = Af^{-5}\exp(-Bf^{-4}) \tag{3.3-1}$$

$$T_m = 0.816B^{-1/4}$$
$$H_s = 2\sqrt{\frac{A}{B}} \tag{3.3-2}$$

Ochi hurricane spectrum (f = Hz)

$$S(f) = \frac{4.5}{(2\pi)^4} g^2 H_s^2 \frac{f_m^4}{f^5}\exp(-1.25\left(\frac{f_m}{f}\right)^4 \left(9.5 f_m H_s^{0.34}\right)^{\exp\left[\frac{-(f-f_m)^2}{2(\sigma f_m)^2}\right]} \tag{3.3-3}$$

Where:

$f_m = 1/T_{modal}$

$\sigma = 0.07$ for $f \le f_m$ and 0.09 for $f > f_m$

$T_{modal} = (T_m / 1.087)/0.7104$

Here, T_m is the mean period that can be defined as 1/average frequency of the spectrum, and T_{modal} is the period at which S(f) has its highest energy density value.

3.3.1 Spectra Construction

The energy density of the hurricane-generated deep water spectrum is concentrated slightly more in the neighborhood of the peak frequency as compared to an ordinary storm spectrum that has slightly wider spread of energy density over frequency. In the case of the Bretschneider spectrum, power density (area under the curve) is a little more spread out than the Ochi's hurricane-generated sea spectrum in Figure 3.12, and this is shown in Figure 3.13. Also, even though this is not clear in Figure 3.13, the Bretschneider spectrum has a large tail region that must be cut off when performing high frequency ship motion analysis as it would otherwise lead to infinite accelerations [21]. These observations make the Ochi's hurricane-generated sea spectrum a better representation of hurricane-generated seas than the Bretschneider spectrum. Nevertheless, both spectra are used for data comparison purposes.

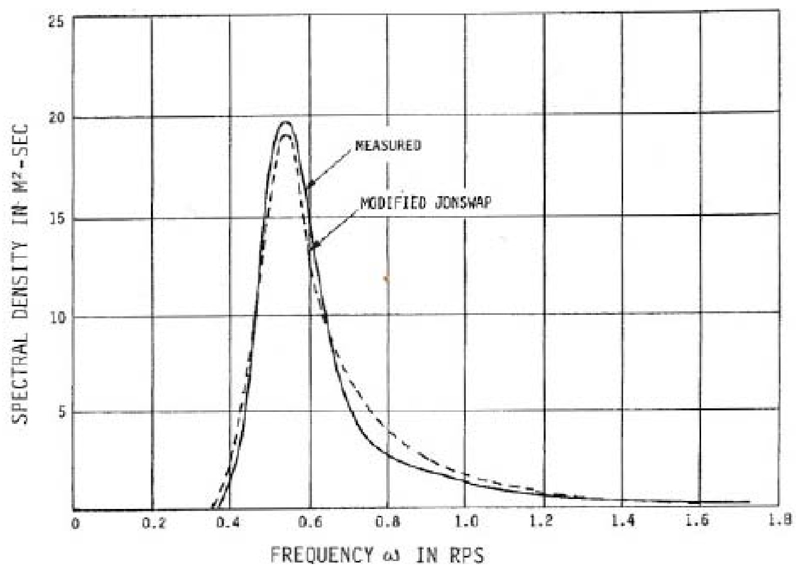

Figure 3.12: Comparison between formulation for hurricane-generated seas and measured spectrum during hurricane ELOISE [30]

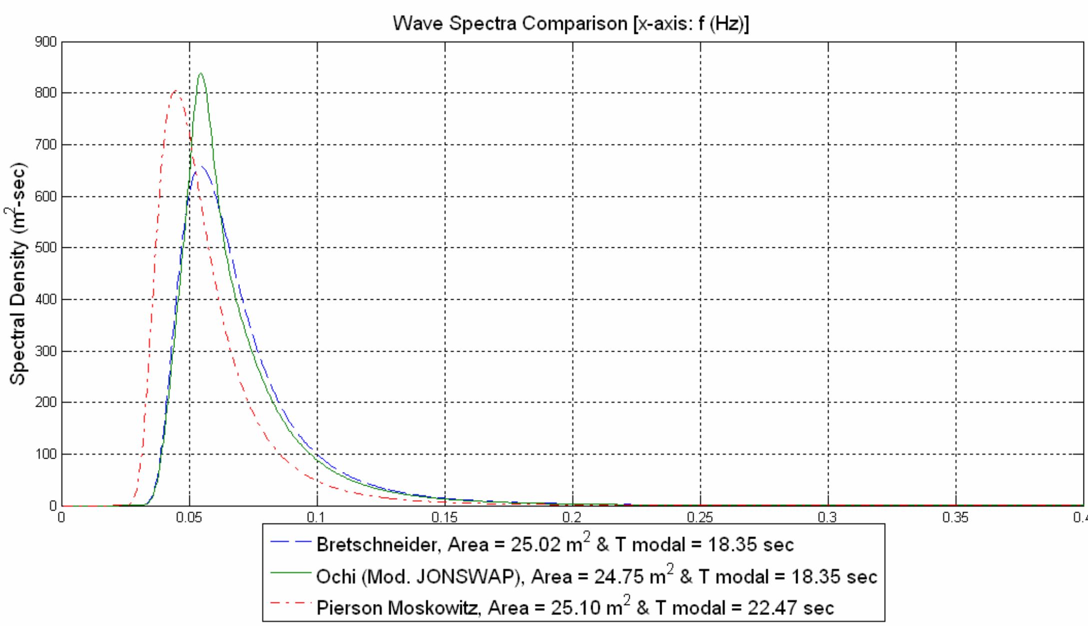

Figure 3.13: Extreme wave spectra comparison (T_m estimated using W2P), 2 deg x 2 deg grid size, 50 yr return period, H_s = 20.01 m, T_m = 14.14 sec (43° N, 163° E)

It is understood that hurricane-generated seas are totally nonlinear, but a lack of measured data in deep water during a hurricane makes verification and model construction difficult. However, a record of measured data available from the North Atlantic during an extremely severe storm with a significant wave height of 16m indicates that the waves are generally Gaussian with limited non-narrow-band properties

[30]. The Ochi's hurricane-generated sea spectrum is based on the assumption that the waves of hurricane-generated seas in deep water are that of a random Gaussian process.

In [30], Ochi makes the following arguments about the hurricane-generated sea spectrum. If hurricane-generated deep water waves were narrow-band Gaussian, then the wave heights observed should follow the Rayleigh probability distribution. However, some of the recent researches indicate that this is not so as their results show that the magnitude of crest is greater than that of trough. Ochi contends that a lot of the wave height records that are reflected in the recent researches were done in finite water depths rather than in deep water, and this questions their applicability to deep water events. Furthermore, although some of the wave measurement records show that the magnitude of peaks is indeed slightly greater than that of troughs, this departure from the Rayleigh distribution is minimal to be a concern. Therefore, Ochi argues that the hurricane-generated extreme waves could be considered a random Gaussian process, which justifies the assumption for Ochi's hurricane-generated sea spectrum.

This certainly is an on-going debate as more and more data become available to support the both sides of the argument. However, it is not one of this thesis' objectives to clarify the validity of Gaussian assumption or linear theory. Rather, the Bretschneider and Ochi's hurricane-generated sea spectra are used in this thesis for their well tested utility as well as ample references describing these two spectra with a clear understanding of their limitations. More discussions on non-linear effects on wave generation are included in Section 5.1.2.

3.3.2 Short Term Order Statistics

Once the spectra are constructed based on extreme significant wave heights and corresponding wave periods, the short term order statistics described by Ochi [31] are used to predict the most probable extreme wave height, extreme H_{prob}. Extreme H_{prob} is defined as the extreme wave height having the highest probability of occurrence during the time duration under consideration. The short term order statistics predicts the extreme value of the maxima of a random process with a given period of time during which the sea condition stays constant. Furthermore, for a linear Gaussian process extreme values as a function of time, T, can be shown as a function only of the area, m_o,

and the second moment, m_2, of the spectral density function pertaining to a random process of interest [31]. The most probable extreme wave amplitude in a dimensionless form is shown in Equation (3.3-4), and a detailed derivation is given in [31]. Equation (3.3-5) gives a dimensional value of the most probable extreme wave height.

$$\bar{\zeta}_n = \sqrt{2\ln\left\{\frac{(60)^2 T}{2\pi}\sqrt{\frac{m_2}{m_0}}\right\}} \tag{3.3-4}$$

$$Extreme\ H_{prob} = 2\cdot\bar{\zeta}_n\sqrt{m_o} \tag{3.3-5}$$

Where:

T = an observation time in hours. In this thesis, this value is set equal to 3 hours, which is a standard interval for measurement.

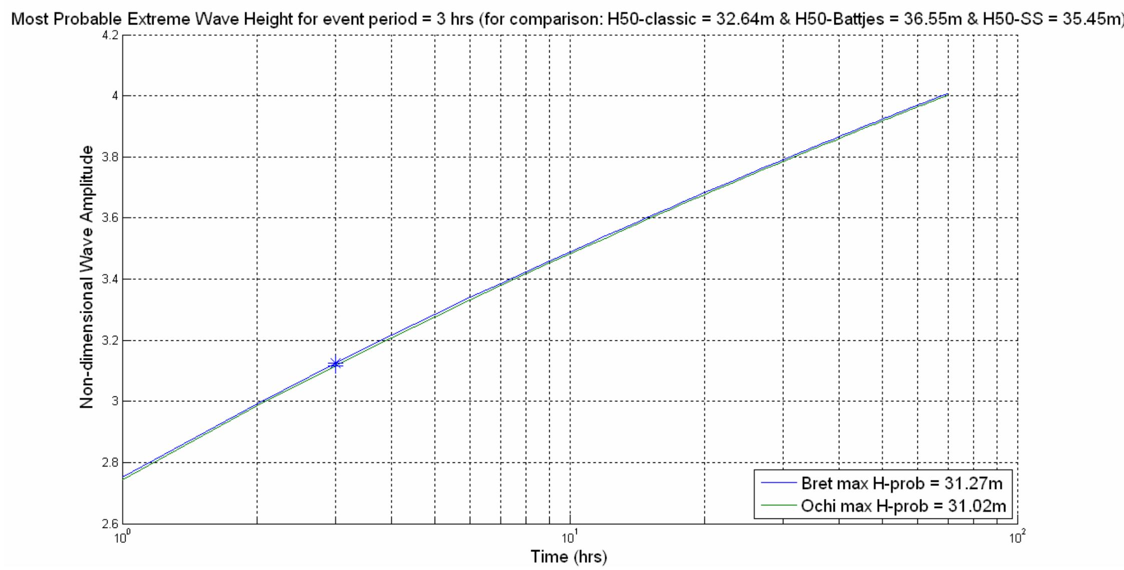

Figure 3.14: Extreme wave amplitude (crest-to-mean) prediction based on short term order statistics (Tm estimated using W2P), extreme H_s from 2 deg x 2 deg grid size, 50 yr return period, H_s = 20.01 m, T_m = 14.14 sec (43° N, 163° E)

The Ochi's method (Equation 3.3-4) gives estimated wave amplitude, and its results are plotted as wave amplitude vs. return period. Figure 3.14 shows an example of this plot for 2° x 2° grid size and the return period of 50 years. The most probable extreme wave amplitude can be estimated by finding a corresponding wave amplitude (y-axis) to a given time period (x-axis) that could be defined as either a return period or a period of observation. It should be noted that simply multiplying the wave amplitude by 2 to get a wave height is not totally accurate as actual wave height measured is likely to

be less than this value, and this is further discussed in Section 5.2. In this thesis, the time period of 3 hours is chosen since it is often used as a standard observation or measurement interval.

Table 3-3: Most probable extreme wave heights (H_s prediction using FT1, T_m prediction using FT1) for H_s = 20.01 m, T_m = 14.14 sec (43° N, 163° E)

Grid size (deg), Return Period	Bretschneider (m)	Ochi (m)	$H_{extreme}$ Classic (m)	$H_{extreme}$ Battjes (modified, m)	**$H_{extreme}$ Seven Stones (m)**	**$H_{extreme} = 2*\zeta_{extreme}$ (simulation, m)**	**$H_{extreme\_max}$ (simulation, m)**
2 x 2, 50 yr	35.76	33.85	32.64	36.55	35.45	35.66	32.06
2 x 2, 100 yr	37.48	35.41	N/A	N/A	N/A	37.52	33.09
4 x 4, 50 yr	33.81	31.93	30.92	34.63	33.60	N/A	
4 x 4, 100 yr	35.43	33.39	N/A	N/A	N/A		

Table 3-4: Most probable extreme wave heights (H_s prediction using FT1, T_m prediction using W2P) for H_s = 20.01 m, T_m = 14.14 sec (43° N, 163° E)

Grid size (deg), Return Period	Bretschneider (m)	Ochi (m)	$H_{extreme}$ Classic (m)	$H_{extreme}$ Battjes (modified, m)	**$H_{extreme}$ Seven Stones (m)**	**$H_{extreme} = 2*\zeta_{extreme}$ (simulation, m)**	**$H_{extreme\_max}$ (simulation, m)**
2 x 2, 50 yr	36.68	36.41	32.64	36.55	35.45	35.66	32.06
2 x 2, 100 yr	38.52	38.28	N/A	N/A	N/A	37.52	33.09
4 x 4, 50 yr	34.68	34.33	30.92	34.63	33.60	N/A	
4 x 4, 100 yr	36.41	36.08	N/A	N/A	N/A		

Table 3-5: Most probable extreme wave heights (H_s prediction using FT1, T_m prediction using the average value of FT1 & W2P) for H_s = 20.01 m, T_m = 14.14 sec (43° N, 163° E)

Grid size (deg), Return Period	Bretschneider (m)	Ochi (m)	$H_{extreme}$ Classic (m)	$H_{extreme}$ Battjes (modified, m)	**$H_{extreme}$ Seven Stones (m)**	**$H_{extreme} = 2*\zeta_{extreme}$ (simulation, m)**	**$H_{extreme\_max}$ (simulation, m)**
2 x 2, 50 yr	36.18	34.98	32.64	36.55	35.45	35.66	32.06
2 x 2, 100 yr	37.96	36.66	N/A	N/A	N/A	37.52	33.09
4 x 4, 50 yr	34.21	32.98	30.92	34.63	33.60	N/A	
4 x 4, 100 yr	35.88	34.56	N/A	N/A	N/A		

The resulting most probable extreme wave heights from short term order statistics for a geographical location (43^o N-163^o E) are summarized in Table 3-3, Table 3-4 and Table 3-5. The table includes the predicted most probable extreme wave heights for the 2^o x 2^o and 4^o x 4^o grid sizes as well as the return periods of 50 and 100 years. Also, the short term order statistics results are based on both the Bretschneider and Ochi's hurricane-generated sea spectra that use the extreme significant wave heights based on the FT1/IDM in [2]. The extreme T_m prediction data using the FT1 and W2P distribution functions and the average value of FT1 and W2P are used to tabulate Table 3-3, Table 3-4 and Table 3-5, respectively. The tables also include the data from other prediction methods as well as wave simulation runs, and they are discussed in Sections 3.3.3 and 3.4. The simulation runs are used only for 2^o x 2^o grid size since it provides better data resolution than the 4^o x 4^o grid. Also, the classic, Battjes, and Seven Stones methods described by Tucker and Pitt [35] only apply to the 50 year return period.

Table 3-3, Table 3-4 and Table 3-5 show very interesting comparisons. First of all, the most probable extreme wave heights predicted by the wave simulation and the Seven Stones equation (Equation 3.3-8) show good agreement, which validates each approach. The most probable extreme wave heights based on short term order statistics vary relative to the other prediction methods depending on the T_m prediction methodology. Since all the methods listed in Table 3-3, Table 3-4 and Table 3-5 use the same extreme significant wave height data from Alves and Young [2], the main difference between the short term order statistics and the other methods can only be due to the mean wave period, T_m. From Table 3-2, it can be seen that the extreme T_m value based on FT1 is longer than that of a simulation run and the extreme T_m value based on W2P is shorter than the simulation value whereas the average of these two values is close to the simulation value. Interestingly, these observations result in the extreme wave values based on the FT1 T_m prediction being lower than the values based on the methods described by Tucker and Pitt [35] or the wave simulation. In the case of the W2P T_m prediction, the predicted extreme wave heights are higher, and the predicted extreme wave heights based on the average values of FT1 and W2P are even closer to the values from the other methods and the wave simulation as shown in Table 3-4 and Table 3-5.

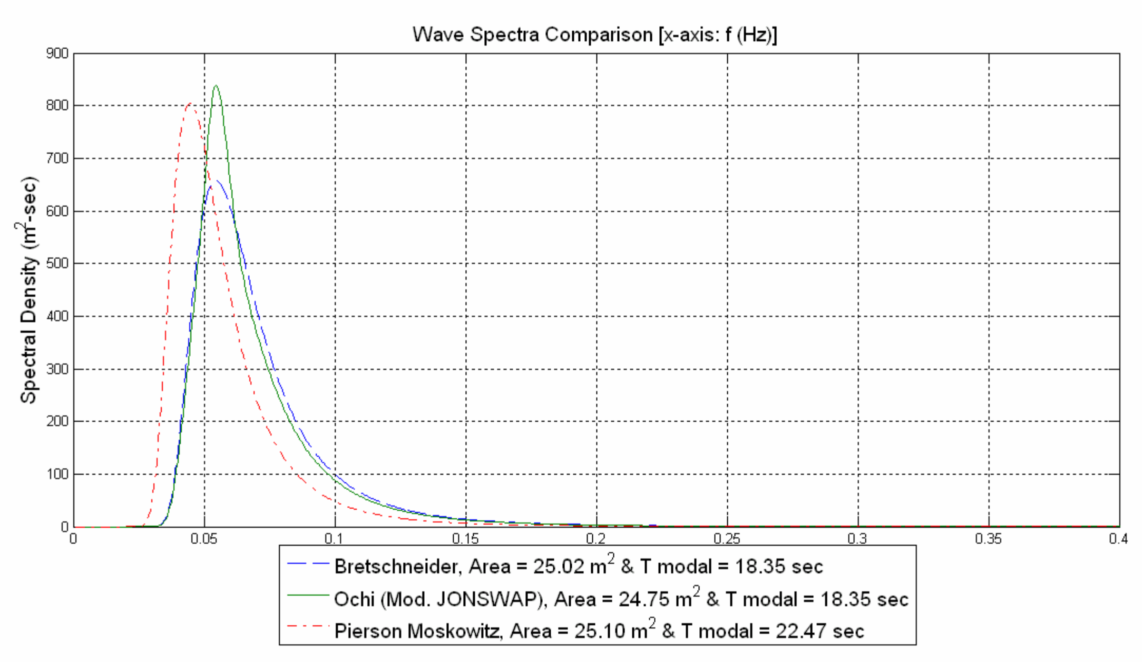

Figure 3.15: Wave amplitude spectra comparison (T_m prediction using W2P) , 2 deg x 2 deg grid size, 50 yr return period, H_s = 20.01m, T_m = 14.14 sec (43° N, 163° E)

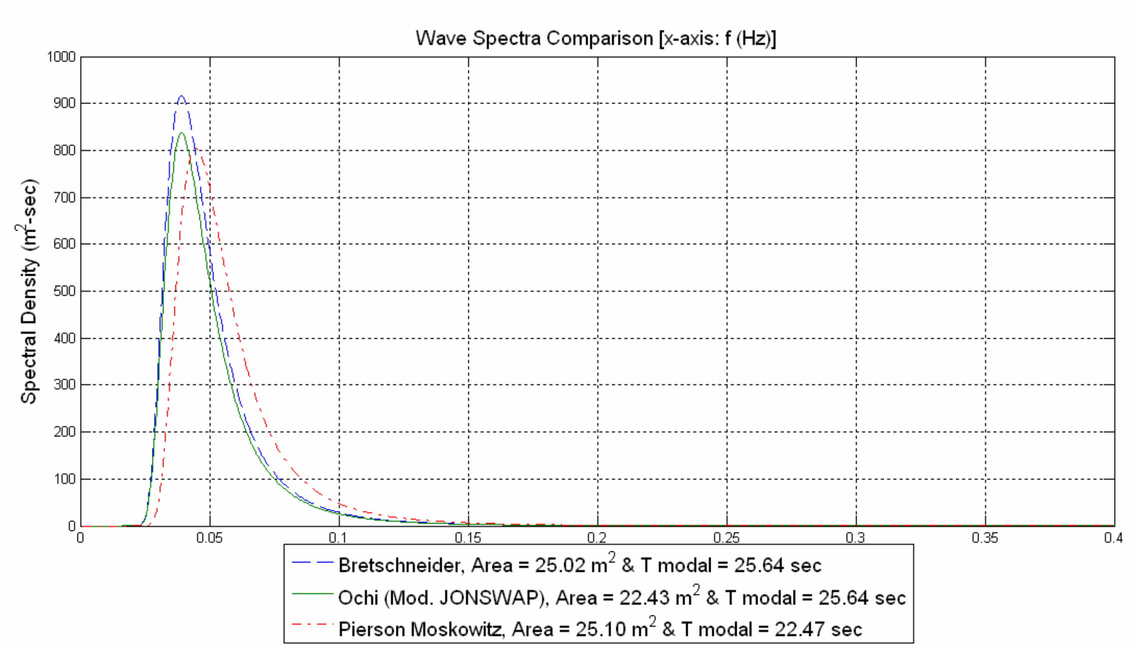

Figure 3.16: Wave amplitude spectra comparison (T_m prediction using FT1) , 2 deg x 2 deg grid size, 50 yr return period, H_s = 21.03m, T_m = 19.73 sec (43° N, 163° E)

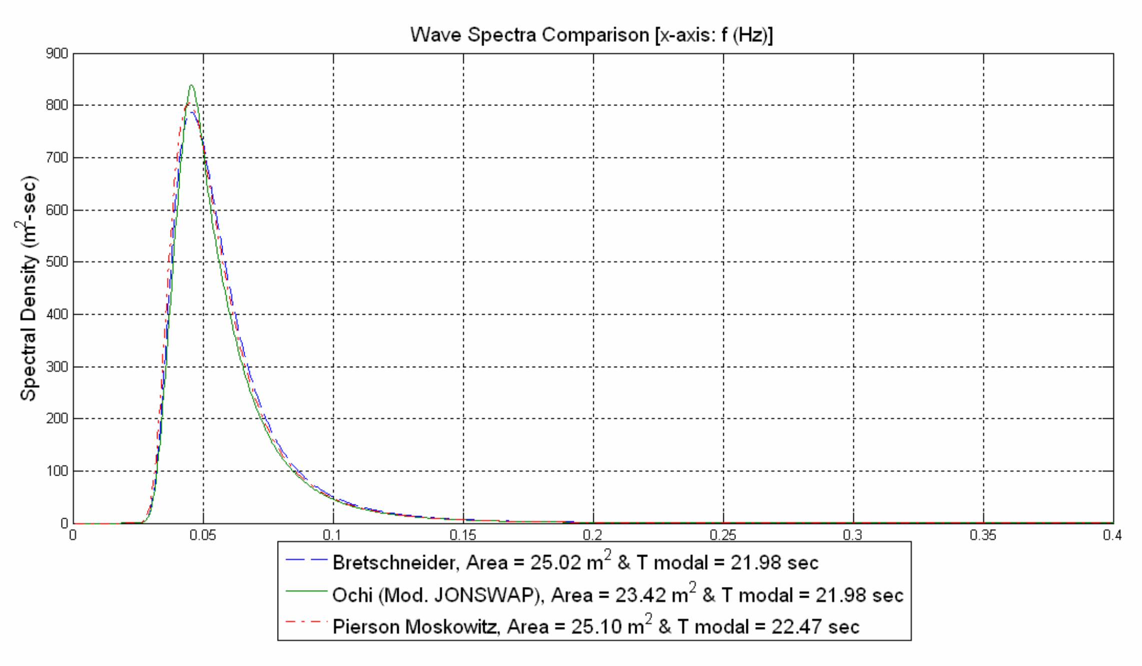

Figure 3.17: Extreme wave spectra comparison (T_m estimated using the average of FT1 and W2P), 2 deg x 2 deg grid size, 50 yr return period, H_s = 20.01 m, T_m = 14.14 sec (43° N, 163° E)

The relative differences in magnitudes of predicted extreme wave heights based on mean wave period prediction methodologies can be explained by the shapes of corresponding spectra as shown in Figure 3.17, Figure 3.15 and Figure 3.16. The two parameter spectra based on the extreme T_m values from FT1 lie left to the Pierson-Moskowitz spectrum (Figure 3.15), and it is the opposite for the case of the extreme T_m values based on W2P (Figure 3.16). Because these shifts correspond to higher or lower energy density for each spectrum due to the shifts along the frequency range, the spectra based on the FT1 T_m prediction result in lower estimated extreme wave heights than the ones based on the W2P T_m prediction method. Because the wave simulation is based on the Pierson-Moskowitz spectrum, which is a one parameter spectrum that does not depend on wave period data, the spectrum stays constant relative to the two parameter spectra. Interestingly enough, when the spectra are constructed using the average values of T_m predicted by both FT1 and W2P, the Bretschneider and Ochi's hurricane-generated sea spectra match quite well with the Pierson-Moskowitz spectrum (Figure 3.17), and the resulting closely matched predicted extreme H_{prob} are shown in Table 3-5. Although using the average extreme T_m values yields surprisingly close results, this approach is not validated as part of this thesis. However, even the extreme T_m values based on the W2P distribution function seem to provide the values within an acceptable range (± 5%). This

is very encouraging, and the comparisons with other prediction methods also show acceptable results from using short term order statistics.

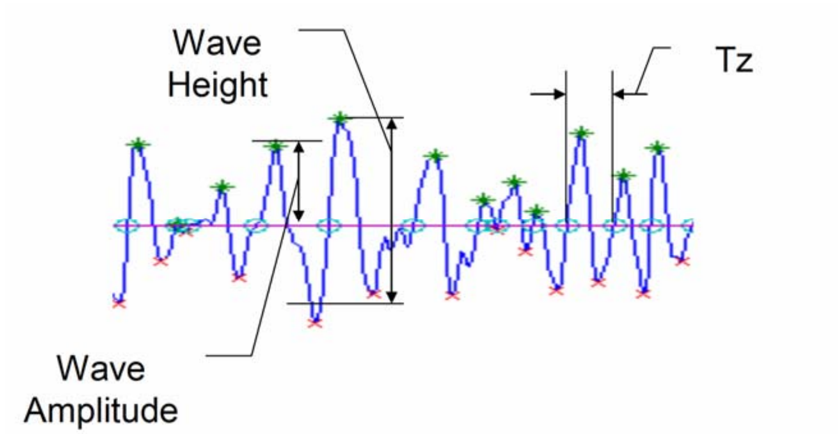

Figure 3.18: Wave parameters

One last observation from the above tables is the difference between $H_{extreme}$ and $H_{extreme\_max}$. For the wave simulation, $H_{extreme}$ is calculated by doubling the maximum crest height whereas $H_{extreme\_max}$ is found by actually measuring the distance between the local crest maximum to the adjacent local trough minima as shown in Figure 3.18.[2] The $H_{extreme\_max}$ value actually is less than $H_{extreme}$, and this is due to the fact that the maximum crest and the minimum trough are highly unlike to be co-located as discussed in Section 5.2. So doubling either the maximum crest height or the minimum trough height (both having identical probability distribution since the linear theory is assumed) will be most likely greater than the measured maximum crest-to-trough height. The extreme H_{prob} data based on the T_m extrapolation are calculated by doubling the wave amplitude, and this should be carefully considered when choosing a design wave height.

3.3.3 Other Prediction Methods

There are other extreme wave prediction methods that can provide a quick way of approximating extreme H_{prob} when extreme significant wave heights are known. These methods are the classic H_{50} for the 50 year return period, modified Battjes, and the

[2] Each simulation here was run for a 3 hour period since this was the data collection period used for the short term order statistics. If this period were extended to 3 days, the most probable wave height is actually greater than that of the 3 day period as seen in Appendices A and B.

empirical relationship derived at the Seven Stones site as described by Tucker and Pitt [35]. The focus here is not to validate these methods but to simply use them to check how close the predicted values of extreme H_{prob} by this approach are to other methods that are used for quick initial design decisions.

The classic, modified Battjes, and Seven Stones equations offer rough estimates of extreme or design wave heights for given extreme significant wave heights with the return period of 50 years [35]. The classic method (Equation 3.3-6) is based on the FT1 distribution function. It assumes a measurement interval of 3 hours, and it is derived using the similar procedure as what has been followed (estimate $H_{s,50}$, construct a CDF, line fitting, extrapolation, etc.). The method also assumes the Rayleigh distribution but with a correction value K, which corresponds to a reduced RMS value. For the narrow band case, the K value of 1 is used, and in the case of extreme storms for the few highest waves, the K value of 0.9 is typically used [8]. For this comparison, the K value of 0.9 is used. The estimate of individual extreme wave height with a return period of 50 years based on the classic method is shown in Equation (3.3-6)

$$H_{50,Classic} = KH_{s50}\sqrt{4.033 - \frac{\ln H_{s50}}{4}} \qquad (3.3\text{-}6)$$

The modified Battjes method is more sophisticated than the classic method, and its approach is not as simple as the classic method. However, there exists a relationship between the modified Battjes and the classic methods that shows the wave heights predicted by the modified Battjes method is consistently higher than those predicted by the classic method by 12% with a confidence level of ±1% [35]. Therefore, a rather simple equation can be derived based on this relationship. This is very convenient because the classic method is much easier to use than the modified Battjes, and this relationship is shown in Equation (3.3-7). This empirical relationship is only valid for the FT1 distribution.

$$H_{50,\ Battjes} = 1.12 * H_{50,\ Classic} \qquad (3.3\text{-}7)$$

The Equation 3.3-8 is derived from an empirical relationship found at the Seven Stones site northeast of the Scilly Isles [35]. This relationship between the measured data and the modified Battjes method assumes treating each 3-hour period as an event and a significant steepness of 1/18. This is only a rough estimate, and it should be applied as such.

$$H_{50,\ \text{Seven Stones}} = 0.97 * H_{50,\ \text{Battjes}} \quad (3.3\text{-}8)$$

3.4 Wave Simulation

3.4.1 Wave Simulation

A wave simulation based on the Fast Fourier Transform provides a way of validating the most probable extreme wave height prediction model as well as another way of predicting environmental data associated with rare extreme waves. There already exist many sophisticated numerical modeling tools such as WAM that are being used extensively. However, a simple Matlab code such as the one used in this thesis can offer a quick way of validating one's approximation and even estimating rough design parameters before proceeding to more detailed design studies. The original Matlab code was written by Prof. Jerome Milgram, and it has been modified by the author for this thesis. Some of the code is included in Appendix C.

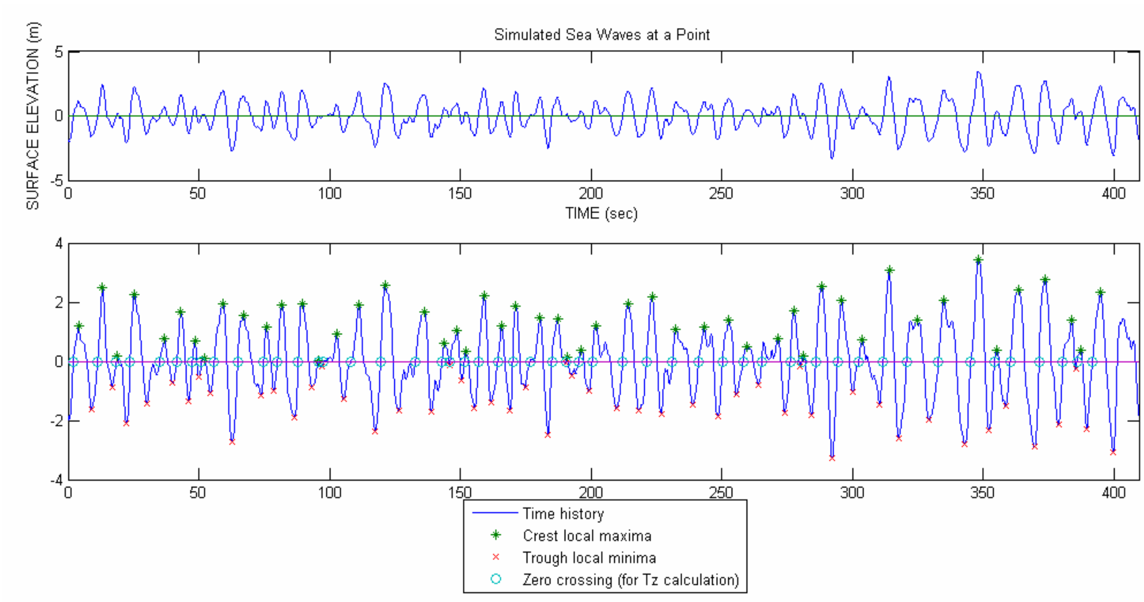

Figure 3.19: An example of wave simulation using the Pierson-Moskowitz spectrum (Matlab)

A wave simulation using the Pierson-Moskowitz spectrum can provide a time history data of wave heights at a point using unidirectional wave train. Within each

simulation run as shown in Figure 3.19, a total of 30 spectra are created to assure randomness and statistical reliability of the data. At first, a total of 100 spectra were used, but computation time was too excessive. Besides, the results from the 30 simulation runs didn't deviate much from that of the 100 runs, and therefore, 30 simulation runs seemed acceptable. A particular measurement such as the maximum wave crest amplitude is measured for each spectrum, and then they are averaged over the 30 measurements to calculate a mean value. Some of the measurements available from the simulation run are the maximum wave crest amplitude, the maximum wave height, and zero-crossing period. Maximum wave height is measured from the local crest maxima to the average of two adjacent trough minima as shown in Figure 3.18.

The simulation uses the Fast Fourier Transform (FFT) with the following parameters. The upper bound of frequency domain is decided based on the minimum wave length of interest, which in this case is 10 meters. Then using Equation (3.4-1), the f_{max} can be calculated. Only the upper bound of frequency domain needs to be calculated, and this is done to eliminate high frequencies that create ripples that do not generally affect the overall shapes of large waves. In addition, this would significantly reduce the memory requirements for computation, which in turn, would make the simulation run faster. The number of data points, N, corresponding to a 3 day period in seconds is based on Equation (3.4-2).

$$f_{\max} = \sqrt{\frac{g}{2\pi\lambda_{\min}}} \tag{3.4-1}$$

$$N = f_{\max} T \tag{3.4-2}$$

Validation

Before using the wave simulation to verify the most probable extreme wave height results from the T_m prediction technique in Section 3.3, the simulation itself needs to be validated, and three different types of spectra are used for the validation runs: the Pierson-Moskowitz, Bretschneider and Ochi's hurricane-generated sea spectra. The results from the validation runs using the 43^o N-163^o E, 2^o x 2^o grid size, and the extreme

H_s with the 50 year return period from Alves and Young [2] are shown in Table 3-6.[3] For each spectrum, the simulation is run for 3 days and each run is repeated 30 times to ensure statistical reliability of the results, which are then averaged. In Table 3-6, extreme H_s and mean zero-crossing periods, T_z (Equation 3.4-3) are used for validation. For each spectrum, extreme significant wave height is calculated using Equation (3.4-4) based on the zeroth spectral moment or the area of energy density function as well as Equation (3.4-5) that uses variance of the actual wave amplitude measurements, ζ, from the simulation runs.

Zero-crossing period

$$T_z = 2\pi\sqrt{\frac{m_o}{m_2}} \tag{3.4-3}$$

Significant wave height

$$H_s = 4\sqrt{m_0} \tag{3.4-4}$$

$$H_s = 4\sqrt{\overline{\zeta^2}} \tag{3.4-5}$$

Where:

$$m_0 = \int_0^\infty S(f)\,df \tag{3.4-6}$$

The Pierson-Moskowitz Spectrum (using significant wave height, H_S)

$$S(f) = 0.0081 g^2 (2\pi)^{-4} f^{-5} \exp\left[-\beta\left(\frac{f_o}{f}\right)^4\right] \tag{3.4-7}$$

Where:

$$f_o = \frac{g}{\left(2\pi\sqrt{\frac{H_s}{0.0213}}\right)} \tag{3.4-8}$$

[3] All the simulation runs are based on 2° x 2° grid elements for Alves and Young's [2] extreme significant wave height data.

Table 3-6: Wave simulation run validation for the 2 deg x 2 deg grid size and the 50 and 100 yr return periods (43^o N, 163^o E)

		Pierson-Moskowitz	Bretschneider	Ochi
50	Extreme H_s, m (Alves & Young)	20.01	20.01	20.01
	Extreme H_s calculated, m [4*sqrt(m_0)]	20.00529724491726	19.97735043133674	19.27243325893936
	Extreme H_s measured, m [4*sqrt(zeta^2)]	20.00529723128135	19.97735041772263	19.27243326794030
	T_z mean calculated, sec [2π*sqrt(m_0/m_2)]	16.41	16.41	16.57
	T_z mean measured, sec (zero-crossings)	16.96	16.96	17.13
100	Extreme H_s, m (Alves & Young)	21.03	21.03	21.03
	Extreme H_s calculated, m [4*sqrt(m_0)]	21.02831170863908	20.99893855159861	20.23418257810009
	Extreme H_s measured, m [4*sqrt(zeta^2)]	21.02831170793596	20.99893855090898	20.23418290072059
	T_z mean calculated, sec [2π*sqrt(m_0/m_2)]	16.80	16.80	16.96
	T_z mean measured, sec (zero-crossings)	17.34	17.34	17.51

The results from the validation runs are encouraging as all the results show close correlation to the extreme H_s estimated by Alves and young [2]. The decimal places for extreme H_s results from the simulation runs are included only to show the closeness as well as the difference between the calculated and measured values, and they do not represent precision. The Pierson-Moskowitz spectrum gives the closest matching values compared to the extreme H_s, and it is closely followed by the Bretschneider spectrum and the Ochi's hurricane-generated sea spectrum. For zero-crossing periods, the Pierson-Moskowitz and the Bretschneider calculate the same values and compare well with the measured values whereas the disparity in measured and calculated values for the Ochi's spectrum is greater than the other two spectra. Overall, the runs have successfully validated the wave simulation as an acceptable first order approximation of extreme waves.

Here, a brief discussion about the three spectra is warranted. The Pierson-Moskowitz spectrum (Equation 3.4-6) is probably the most widely used formula, and it is a one-parameter spectrum that requires one input variable, which can be either mean wind speed or significant wave height or wave period. The Bretschneider spectrum, which is the generalized Pierson-Moskowitz spectrum, and the Ochi's hurricane-generated sea spectrum are two parameter spectra that require significant wave height and

wave period inputs. Figure 3.15 and Figure 3.16 in Section 3.3.2 show the differences between the three spectra. Figure 3.15 shows the two parameter spectra based on the extreme T_m from the W2P distribution function and Figure 3.16 is based on the extreme T_m from the FT1 distribution function. In Figure 3.15, the spectra peaks of the Bretschneider and Ochi's hurricane-generated sea spectra are shifted to the right of the Pierson-Moskowitz spectrum, which result in higher most probable extreme wave height predictions as discussed in Section 3.3.2. In Figure 3.16, this is the opposite, and it results in lower predicted values. When the average extreme T_m value from FT1 and W2P is used, the spectral peaks almost line up perfectly as shown in Figure 3.17. For the wave simulation validation runs, the extreme T_m values from the Pierson-Moskowitz spectrum are used in order to align the spectral peaks of three spectra. This way, the comparison of the three spectra can be done uniformly. Also, the results from the simulation runs can be independent of those based on the predicted extreme T_m values, and this would allow the most probable extreme wave height prediction model in Section 3.3 to be validated using these results.

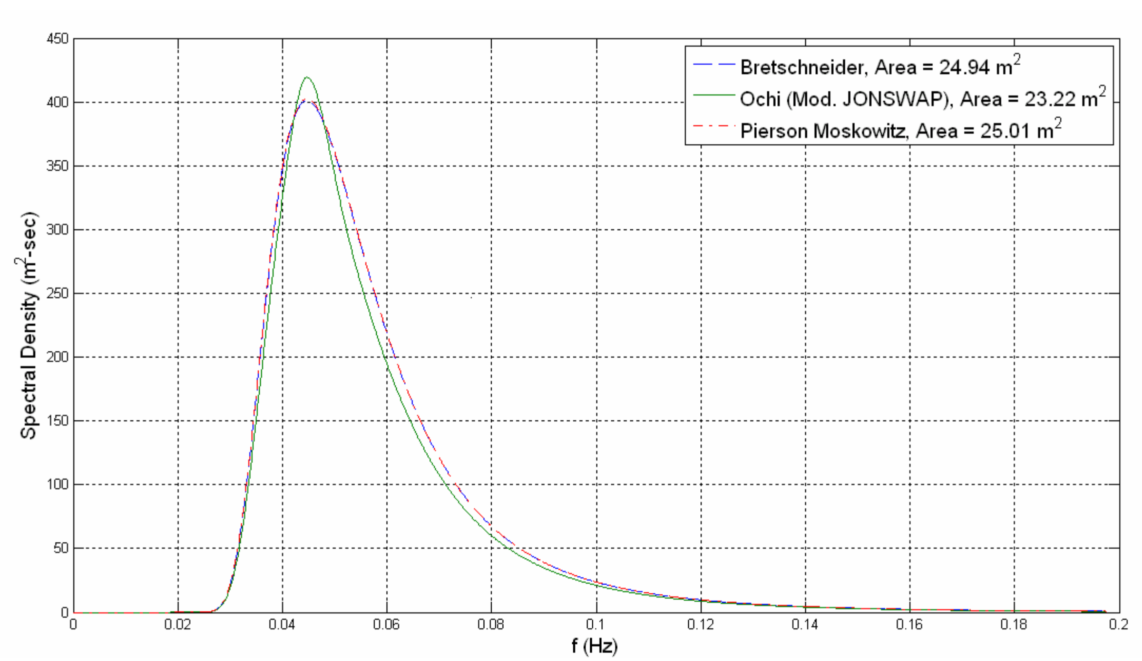

Figure 3.20: Wave amplitude spectra reconstruction using the modal period, T_m from the Pierson-Moskowitz spectrum, 2 deg x 2 deg, the 50 yr return period (43° N, 163° E)

For the simulation validation runs, the wave period measurements from the Pierson-Moskowitz spectrum are used for the Bretschneider and Ochi's hurricane-generated sea spectra, and this is shown in Figure 3.20. Since the same wave period is used for all three spectra, the plots show good agreement of the modal periods that correspond to the maximum values of spectral density functions, S(f) or spectral peaks. Furthermore, because the Bretschneider spectrum is based on the Pierson-Moskowitz spectrum, they almost completely overlap each other in these plots, and this explains the close agreement of zero-crossing period values that are shown in Table 3-6. The Ochi's spectrum shows a slightly narrower band width with a sharper peak that is a representative of hurricane-generated sea spectrum.

Although the Ochi's hurricane-generated sea spectrum is specifically designed for extreme sea conditions, based on the results of the validation runs in Table 3-6 and more importantly, the effort to isolate the possible errors with the T_m prediction model in Section 3.2, the Pierson-Moskowitz spectrum that does not require wave period input is chosen for the subsequent simulation runs. The significant wave height comparison using the Pierson-Moskowitz spectrum yields the closest match with the input extreme H_s. Furthermore, it is a one-parameter spectrum that eliminates the need for an extreme wave period input that is currently not available as measured data. Because it does not require wave period, the spectrum can be effectively used to validate the spectral approach that is discussed in Sections 3.2 and 3.3, and this is the main reason why it is chosen for the wave simulation. Lastly, even though the spectrum contains a slightly wider bandwidth than the Ochi's, this difference is minimal, and since the Bretschneider spectrum, which is based on the Pierson-Moskowitz spectrum, is widely used for storm seas, the Pierson-Moskowitz spectrum is an acceptable choice in this case. The results from the simulation runs are tabulated and included in Appendices A and B.

3.5 Deep Water Breaking Waves (Fluid Velocity and Acceleration)

One aspect of extreme waves that is of a special interest is breaking waves. Breaking waves are important in ocean engineering and naval architecture because of their heights, lengths, fluid velocities and fluid accelerations. These quantities influence the seaworthiness of boats, ships and ocean working platforms. Capsizing of boats and

ships is of particular concern. Wave conditions that exceed the Safe Operating Envelope (SOE) need to be known by operators of these vessels and platforms.

Any of the preceding analysis that depends on a Gaussian probability distribution for surface elevation does not apply in the presence of breaking waves. However, the satellite altimeter data does give significant wave heights, including the effects of breaking.

Fluid velocities and accelerations can be approximated up to the start of wave breaking by nonlinear numerical computation if the effects of wind stress, vorticity and viscosity are ignored. Under these "idealized conditions," Cokelet [11] calculated that periodic waves begin to break when their wave slope equals 0.141. In actual sea conditions with many wave periods present and in the presence of storms, waves begin to break at considerably smaller slopes.

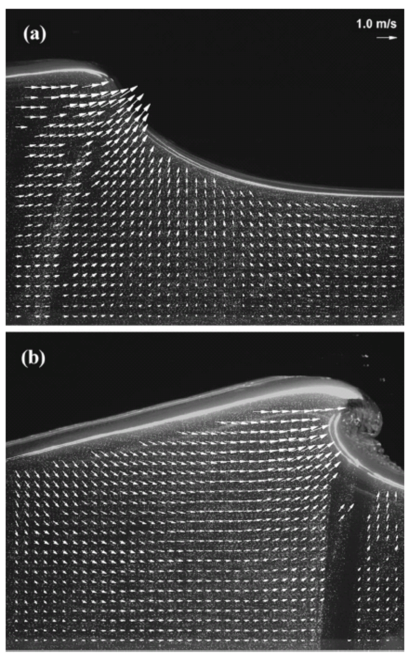

Figure 3.21: Velocity field under a near-breaking wave at t = (a) 1.388 s and (b) 1.562 s [10]

Steep real waves are very nonlinear, which makes the direct study of the hydrodynamics of breaking waves difficult. Figure 3.21 shows part of the evolution of the flow field in a periodic breaking wave in a laboratory wave tank. Because it is not practical to build a sufficiently large wind-wave tank, the required study involves full

scale experiments at sea in order to include all the oceanic effects that do not exist in the laboratory. Some prior knowledge of expected sea conditions can be very useful in planning for such experiments albeit part of this is based on linear theory.

Linear waves are a good approximation for waves with gentle slopes, but they do provide limited insight into the phenomenon of breaking waves. Splashing, turbulence and air entrapment that occur once a wave breaks can not be easily modeled by computation based on known theory. What little of numerical modeling that is available is limited to flows with zero or constant vorticity that do not accurately represent the violent nature of deep water large breaking waves [5]. However, Banner and Peregrine [5] noted that some simple models of spilling breakers do seem to give reasonable results.

As previously described, extensive radar altimeter data from satellite have provided a good measure of the statistics of significant wave heights at sea. Unfortunately, the data provides no information about the fluid flow field kinematics in severe sea states. In this thesis, these data have been used to construct wave spectra from which random records of surface elevation are computed assuming the waves obey linear theory and are long crested. These spectra are then used to construct the fluid flow field since fluid acceleration is more important than wave height as far as ship seakeeping is concerned (a ship will merely heave gently on very long wave even if they are high).

$$S_v(f) = (2\pi f)^2 S(f) \tag{3.5-1}$$

$$S_a(f) = (2\pi f)^4 S(f) \tag{3.5-2}$$

Table 3-7: RMS velocity and acceleration, 2 deg x 2 deg grid size (43^o N, 163^o E)

		50 yr return period	100 yr return period
Pierson-Moskowitz	Velocity, RMS(m/s)	1.915	1.966
	Acceleration, RMS (m/s^2)	1.002	1.011
Ochi	Velocity, RMS(m/s)	1.828	1.875
	Acceleration, RMS (m/s^2)	0.948	0.957
Bretschneider	Velocity, RMS(m/s)	1.913	1.964
	Acceleration, RMS (m/s^2)	1.001	1.010

Using the wave elevation spectra and linear theory, the surface vertical velocity spectra as well as the surface acceleration spectra can be generated. Equation (3.5-1) shows the surface vertical velocity spectrum, $S_v(f)$, and the surface vertical acceleration spectrum, $S_a(f)$, is shown in Equation (3.5-2). Examples of the vertical velocity and acceleration spectra are shown in Figure 3.22 and Figure 3.23, respectively. Here, it is necessary to cut off the high frequency tail of the spectrum to avoid unrealistic infinite surface accelerations. Records of up to 3-day random surface acceleration time histories are then computed as shown in Table 3-7 in the same way as the elevations, except that the acceleration spectra are substituted for the elevation spectra in the simulation runs as discussed in Section 3.4.1. The step of extending this to short crested (confused) seas obeying linear theory is straightforward. Beyond that, the equations needed to extend the results to second order are known, and for limited circumstances others have written and used computer programs to obtain the kinematics up to second order. Making this approach general could certainly be done, but the computational demands would be enormous. It would certainly be a worthwhile endeavor if the effects of wind, vorticity and viscosity and especially wave breaking could be neglected. However, since these effects, particularly those of spilling breaking waves are undoubtedly important, extensive experiments are necessary.

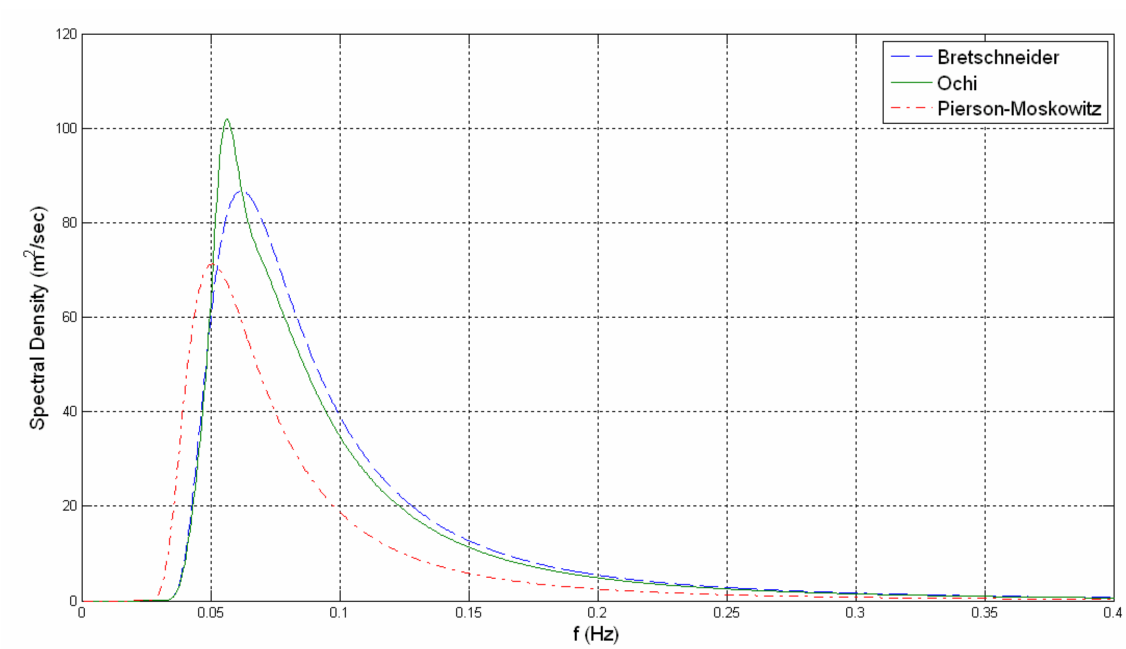

Figure 3.22: Wave vertical velocity spectra comparison (T_m prediction using W2P) , 2 deg x 2 deg grid size, 50 yr return period, H_s = 20.01m, T_m = 14.14 sec (43° N, 163° E)

One of the main objectives of this thesis is to develop a wave velocity and acceleration field data based on wave elevation spectra, which can be used for seakeeping analysis as well as future planning of deep water experiments to observe large breaking waves. Since the approach taken in this thesis does not involve any detail laboratory experiments or in-situ measurements, only vertical velocity and acceleration of unidirectional waves based on linear theory have been considered. Once a wave elevation spectrum is known, RMS values of vertical velocity and acceleration can be easily calculated from the velocity and acceleration spectra along with other statistical information. Here, an important approximation can be made, and it is that the vertical velocity spectrum in longitudinal (i.e. two dimensional) non-breaking seas is approximately equal to the horizontal velocity spectrum in the same environment, and the same applies to acceleration spectrum. The average velocity and vertical acceleration data are tabulated in Appendices A and B using the Pierson-Moskowitz spectrum. The applicability of the data based on linear theory is certainly limited. However, this step is taken to create a wave field simulation that could be used as a design tool for any future open ocean experiments to study deep water wave breaking phenomenon.

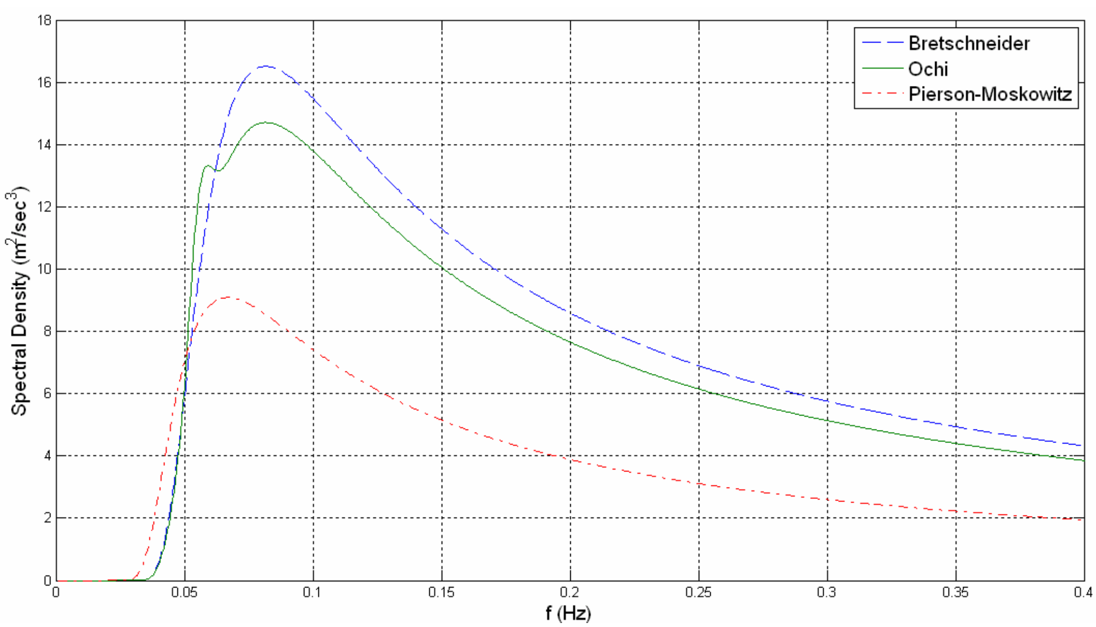

Figure 3.23: Wave vertical acceleration spectra comparison (T_m prediction using W2P), 2 deg x 2 deg grid size, 50 yr return period, H_s = 20.01m, T_m = 14.14 sec (43° N, 163° E)

4 Extreme Environmental Data

Not only does availability of extreme ocean environmental data benefit the understanding of extreme waves, but it also aids greatly in designing marine systems and structures and identifying their operating limitations. Furthermore, the data can be also used for design of deep water experiments regarding extreme and rare waves. Although the methodologies mentioned in this thesis thus far have led to constructing spectra based only on linear approximation, the statistical results from them are in good agreement with other methods available for quick engineering assessments as seen in Table 3-3, Table 3-4 and Table 3-5. Having wave data based on linear approximation offers far more advantage than having no wave information at all. And, while the new technology such as Synthetic Aperture Radar (SAR) continues to improve on measurement of waves with resolutions much smaller than the length of influential waves, this approximation technique can be used as a good starting point in studying extreme and rare ocean events as part of an ocean system design process.

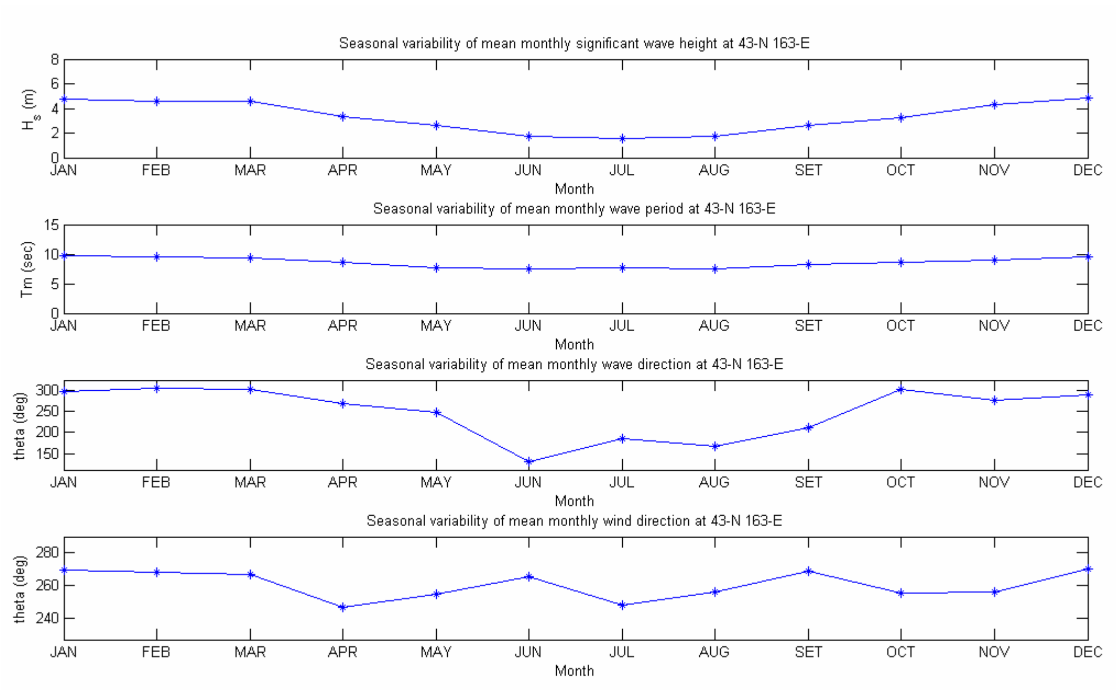

Figure 4.1: An example of data available from the Atlas of the Oceans (43^o N, 163^o E) [2]

Alves and Young's Atlas of the Oceans [2] already contains an extensive ocean environmental database that includes both measured and simulated data. Figure 4.1 is an example of plots that can be generated from the Atlas. In addition to the extreme significant wave height data, Figure 4.1 shows mean monthly significant wave height measured by satellite radar altimeter, mean monthly wave period ($1/f_{ave}$), mean monthly wave and wind directions. These data can be valuable in re-creating extreme ocean conditions and developing certain operating limitations. Furthermore, based on these data, it would be possible to create an approximate directional spectra corresponding to extreme wave environment.

A single parameter spectrum such as the Pierson-Moskowitz spectrum can be easily constructed based on either wind speed or significant wave height whereas a two parameter spectrum like the Bretschneider and the Ochi's hurricane-generated sea spectra require significant wave height and wave period data. The Bretschneider and the Ochi spectra were developed to better represent storm seas than the Pierson-Moskowitz spectrum. In order to take advantage of these two parameter spectra, a way of predicting wave periods corresponding to extreme significant wave heights has been considered in this thesis. Preliminary results indicate that the wave period distribution does not follow existing well-known distribution functions under the IDM application. However, the results also show a great deal of promise as they compare well with the results from other known prediction methods and a wave simulation. Furthermore, using the Pierson-Moskowitz spectrum to estimate wave periods based on satellite measured significant wave heights and extrapolated extreme significant wave heights may provide rough but acceptable estimates of parameters that could be used for spectral analysis. For example, mean or peak wave period data from the Pierson-Moskowitz spectrum based on Alves and Young's extreme H_s [2] or the T_m prediction technique discussed in Section 3.2 can be used to construct the Bretschneider or the Ochi's hurricane-generated sea spectra. Then these spectra can be used to create slope, directional, vertical velocity and acceleration spectra that could be used in other analyses including seakeeping analysis. The slope and directional spectra are briefly discussed in Section 4.2 and Section 4.3.

4.1 Extreme Wave Data

The main goal of this thesis is to construct tables of extreme environmental data that can be used as a quick reference for naval engineering application as well as a preliminary guide for any future deep water experiments regarding large and rare waves. This list includes the following, and they are included in Appendices A and B.

1. Extreme significant wave height prediction by Alves and Young [1][2]
2. Most probable extreme wave height (2 x amplitude) prediction based on the Fisher-Tippett Type 1 (FT1) and the Initial Distribution Method (IDM) for extreme significant wave height extrapolation
   a. Bretschneider spectrum using the Weibull 2-parameter (W2P) distribution functions for mean wave period extrapolation
   b. Ochi's hurricane-generated sea spectrum using the W2P distribution functions for mean wave period extrapolation
   c. Bretschneider spectrum using the average of FT1 and W2P distribution functions for mean wave period extrapolation
   d. Ochi's hurricane-generated sea spectrum using the average of FT1 and W2P distribution functions for mean wave period extrapolation
3. Simulated extreme wave data using the Pierson-Moskowitz spectrum (otherwise noted, each simulation ran for a 3 day duration)
   a. Most probable extreme wave amplitudes for duration periods of 3 hours and 3 days.
   b. Most probable extreme wave weights as measured from crest to trough
   c. Mean zero-crossing wave periods
   d. Mean minimum wave length (Mean minimum wave length is measured from the waves that exceed a threshold value of extreme significant wave height given for each simulation run.)
   e. RMS vertical velocity
   f. RMS vertical acceleration

The list of data covers the North Pacific (21^o – 43^o N, 161^o E – 149^o W) and the North Atlantic (37^o – 57^o N, 19^o – 49^o W). Although Alves and Young's Atlas [2] also include the extreme H_s data based on the W3P/POT method along with the FT1/IDM

method, the list only includes the data based on the FT1/IDM method. Also, Appendices A and B include the data based on both the FT1 and W2P methods as well as their average values of FT1 and W2P for mean period predictions. Table 4-1 and Table 4-2 show the local maximum value for each type of data. The tables also include two storm-duration periods of 3 hours and 3 days. As mentioned in Section 3.3.2, 3 hours is often used as a standard measurement or event period, but it is also common to use 3 days as the duration of any single storm event. The longer duration usually means the higher the predicted wave heights. These data can be used individually or grouped together for spectral analysis.

Table 4-1: Local maxima for the region, North Pacific (21^o – 43^o N, 161^o E – 149^o W)

Type of Data	Extrapolation method	50 yr period	100 yr period
Alves & Young [1] Extreme H_s (m)	2^o x 2^o, FT1 / IDM	22.42	23.57
	4^o x 4^o, FT1 / IDM	21.51	22.6
Most Probable Extreme Wave Amplitude (crest-to-mean sea level) based on T_m prediction (m, **3 hr period**)	2^o x 2^o, W2P for T_m, Bretschneider	20.43	21.45
	2^o x 2^o, W2P for T_m, Ochi	**20.15**	**21.18**
	2^o x 2^o, Average of W2P and FT1 for T_m, Bretschneider	20.13	21.12
	2^o x 2^o, , Average of W2P and FT1 for T_m, Ochi	19.31	20.23
Most Probable Extreme Wave Height (2 x amplitude) based on T_m prediction (m, 3 hr period)	2^o x 2^o, W2P for T_m, Bretschneider	40.85	42.9
	2^o x 2^o, W2P for T_m, Ochi	40.29	42.36
	2^o x 2^o, Average of W2P and FT1 for T_m, Bretschneider	40.25	42.23
	2^o x 2^o, , Average of W2P and FT1 for T_m, Ochi	38.61	40.46
Most Probable Extreme Wave Amplitude based on simulation (m, **3 hr period**)	2^o x 2^o, Pierson-Moskowitz	**21.34**	**22.10**
Most Probable Extreme Wave Amplitude based on simulation (m, **3 day period**)	2^o x 2^o, Pierson-Moskowitz	**24.34**	**25.84**
Most Probable Extreme Wave Height (crest-to-trough) based on simulation (m, 3 day period)	2^o x 2^o, Pierson-Moskowitz	42.58	45.15

Table 4-2: Local maxima for the region, North Atlantic (37^{o} – 57^{o} N, 19^{o} – 49^{o} W)

Type of Data	Extrapolation Method	50 yr period	100 yr period
Alves & Young [1] Extreme H_s (m)	2^{o} x 2^{o}, FT1 / IDM	24.62	25.88
	4^{o} x 4^{o}, FT1 / IDM	23.57	24.77
Most Probable Extreme Wave Amplitude (crest-to-mean sea level) based on T_m prediction (m, 3 hr period)	2^{o} x 2^{o}, W2P for T_m, Bretschneider	22.26	23.37
	2^{o} x 2^{o}, W2P for T_m, Ochi	**21.73**	**22.83**
	2^{o} x 2^{o}, Average of W2P and FT1 for T_m, Bretschneider	21.91	22.98
	2^{o} x 2^{o}, , Average of W2P and FT1 for T_m, Ochi	20.80	21.78
Most Probable Extreme Wave Height (2 x amplitude) based on T_m prediction (m, **3 hr period**)	2^{o} x 2^{o}, W2P for T_m, Bretschneider	44.51	46.74
	2^{o} x 2^{o}, W2P for T_m, Ochi	43.46	45.66
	2^{o} x 2^{o}, Average of W2P and FT1 for T_m, Bretschneider	43.82	45.96
	2^{o} x 2^{o}, , Average of W2P and FT1 for T_m, Ochi	41.59	43.56
Most Probable Extreme Wave Amplitude based on simulation (m, **3 hr period**)	2^{o} x 2^{o}, Pierson-Moskowitz	**23.32**	**24.75**
Most Probable Extreme Wave Amplitude based on simulation (m, **3 day period**)	2^{o} x 2^{o}, Pierson-Moskowitz	**26.67**	**28.11**
Most Probable Extreme Wave Height (crest-to-trough) based on simulation (m, 3 day period)	2^{o} x 2^{o}, Pierson-Moskowitz	46.53	49.65

Spectral analysis is very useful because each spectrum contains a wealth of statistical information, and they can be modified easily depending on what type of data one's interested in. Along with already mentioned velocity and acceleration spectra, wave slope and directional spectra can provide additional information that cannot be extracted simply from individual data sets. They play important roles, especially, in seakeeping analysis, and the examples of these spectra are discussed in Section 4.2 and Section 4.3.

Lastly, it can be seen from Table 4-1 and Table 4-2 that the local maxima are much greater than Sea State 9, which describes wave heights greater than 14 meters. These values will have different design implications depending on whether the marine structure is fixed or free floating. For a free floating structure or a ship, most of the highest waves will be so long that their only influence will be a slow gentle heave motion. Therefore, in establishing safe operating envelopes for a ship, other measures such as wave slope must be used in addition to extreme wave height.

Probability

As part of spectral analysis, Equation (3.6-1) can be use to create the Rayleigh probability distribution that gives the probability of a randomly chosen value H of wave height being placed between h-(dh/2) and h+(dh/2).

$$p(h) = 2\left(\frac{h}{H_r^2}\right)\exp\left(\frac{-h^2}{H_r^2}\right) \qquad (3.6\text{-}1)$$

Where:

H_r = RMS value of h, wave height = $H_s / \sqrt{2}$

Also, the cumulative distribution function can be used in the following from. This gives the probability that a randomly chosen value of H of wave height will be below h, and it is shown in Equation (3.6-2).

$$\begin{aligned} p(H < h) &= \int_0^h p(h)dh \\ &= 1 - \exp\left(-\frac{h^2}{H_r^2}\right) \qquad (3.6\text{-}2) \\ &= 1 - \exp\left(\frac{-2h^2}{H_s^2}\right) \end{aligned}$$

4.2 Wave Slope Spectrum (unidirectional, long-crested)

Many marine systems such as ships and oil platforms show more sensitivity in certain modes of responses, particularly roll, to wave slopes than to wave height [21]. Therefore, in determining sea conditions that could result in catastrophic responses wave slope spectrum is more useful than wave height spectrum. It can be calculated relatively easy using Equation (3.6-3), and an example of slope spectrum is shown in Figure 4.2. This is useful since simulations and statistics derived from the wave slope spectrum have analogous relationships with the wave height spectrum. For example, the variance of wave slope can be calculated by integrating the wave slope spectrum. Also, it can be seen that compared to wave amplitude spectrum, high wave frequencies play a bigger role as shown by a larger area under the tail end of the spectrum. This corresponds to observations that short and high-frequency waves are steeper than long and low-frequency waves although short and high-frequency waves have lower amplitudes. While no further detailed studies on the applications of wave slope spectrum are done as part of this thesis, this clearly shows another utility of spectral analysis.

$$S_{\zeta'}(f) = \frac{(2\pi f)^4 S_\zeta(f)}{g^2} \qquad (3.6\text{-}3)$$

Where:

S_ζ = wave height spectrum

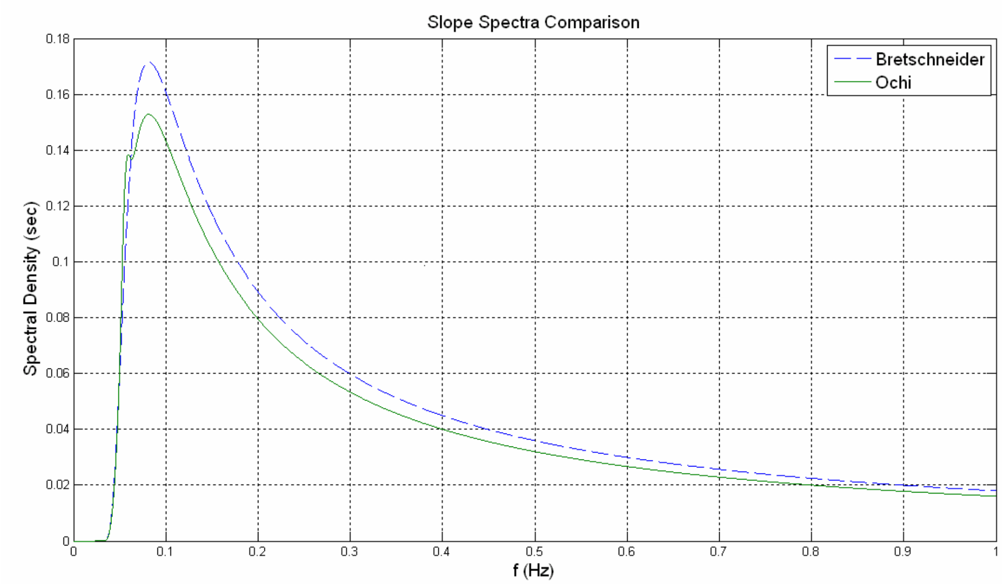

Figure 4.2: An example of extreme wave slope spectrum, 2 x 2 resolution, 50 yr return period, H_s = 20.01 m, T_m = 14.14 sec (43° N, 163° E)

4.3 Directional Spectra

Even though unidirectional waves are easy to construct and therefore, used routinely, these long crested waves that maintain straight and parallel crests do not occur in a real ocean environment. Instead, the real waves travel in many directions with sometimes discernable a “primary” direction, which corresponds more or less to local wind direction. When a wave energy spectrum is concerned, long crested waves can approximate these short crested waves that are the results of enhancement and cancellation of wave crests and troughs, and it is convenient to do so. However, the wave spreading phenomenon greatly affects ship motions, particularly roll, and it cannot be ignored.

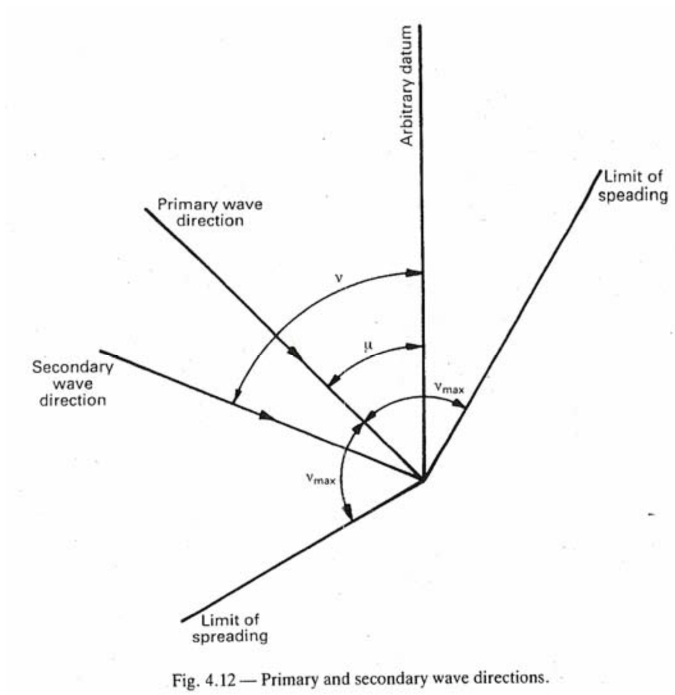

Figure 4.3: Primary and secondary wave directions [22]

$$S(\omega,\nu) = \frac{2}{\pi}\cos^2(\nu-\mu)S(\omega),\ \text{m}^2/(\text{rad/sec}) \text{ per rad, for } (\nu\text{-}\mu) > 0,\ 0 \text{ otherwise} \quad (3.6\text{-}4)$$

The amount of wave spreading corresponding to particular time and place depends on local wind condition as well as geographical factors. There is no finite number of possibilities but for design purposes the secondary wave directions with a certain range is centered around the primary direction as shown in Figure 4.3. It is

assumed that for ship design purposes the directional wave spectral ordinates are related to that of the equivalent total wave energy spectrum $S(\omega)$ as shown in Equation (3.6-4). The value, m, can take on any integer value, but typically m = 2 or "cosine squared" spreading is used since trials evidence suggests it to be appropriate for typical ocean wave conditions [22]. However, for well directed waves, m = 4 is sometimes used as well. Also, $\nu_{max} = 90^o$ are used in conjunction with m = 2 to represent short crested waves for design purposes even though ν can rage from 60 degrees to 120 degrees as shown in Figure 4.4, Figure 4.5 and Figure 4.6. Equation (3.6-4) shows the relationship between the directional wave spectral ordinates and the ship angle with respect to the wind. Often, a faster-computing approach is to represent a directional sea as the sum of a few unidirectional seas, each with its own spectrum, and this is shown in Equation (3.6-5). The corresponding spreading weighting factor, W, is given in Table 4-3 where the weighting factors are for $\delta\nu = 15^o$, $\nu_{max} = 90^o$ and m = 2.

$$\text{Spreading } S(\omega) = W^*S(\omega),\ m^2/(\text{rad/sec}) \qquad (3.6\text{-}5)$$

Table 4-3: Weighting factors from calculations of ship motions in short crested waves [22]

ν - μ	W
$\pm 90^o$	0.000
$\pm 75^o$	0.011
$\pm 60^o$	0.042
$\pm 45^o$	0.083
$\pm 30^o$	0.125
$\pm 15^o$	0.156
0	0.167

The values of weighting factor, W, are available in a tabulated format for $\delta\nu = 15^o$, ν_{max} = 60, 90 and 120 degrees and m = 0, 1, 2, 5, 10 and 20 [22]. As it is with wave slope spectrum discussed in Section 4.2, no in-depth studies on directional spectra are done as part of this thesis. It is mentioned here to demonstrate another application of spectral analysis that can be useful, especially, in seakeeping analysis. Some of example plots are shown in Figure 4.4, Figure 4.5 and Figure 4.6.

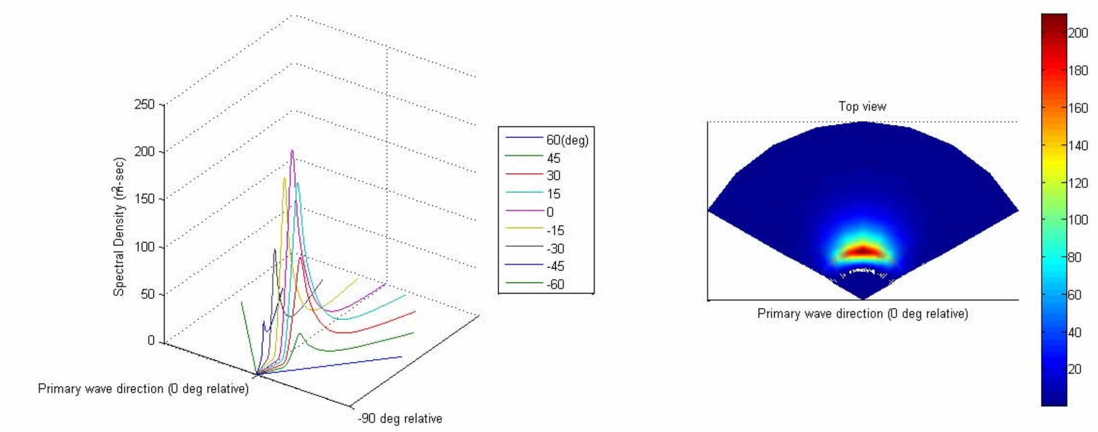

Figure 4.4: Directional Ochi hurricane spectra, 2 deg x 2 deg grid size, 50 yr return period, 60 degree spreading, m = 2, H_s = 20.01m, T_m = 14.14 sec (43^o N, 163^o E)

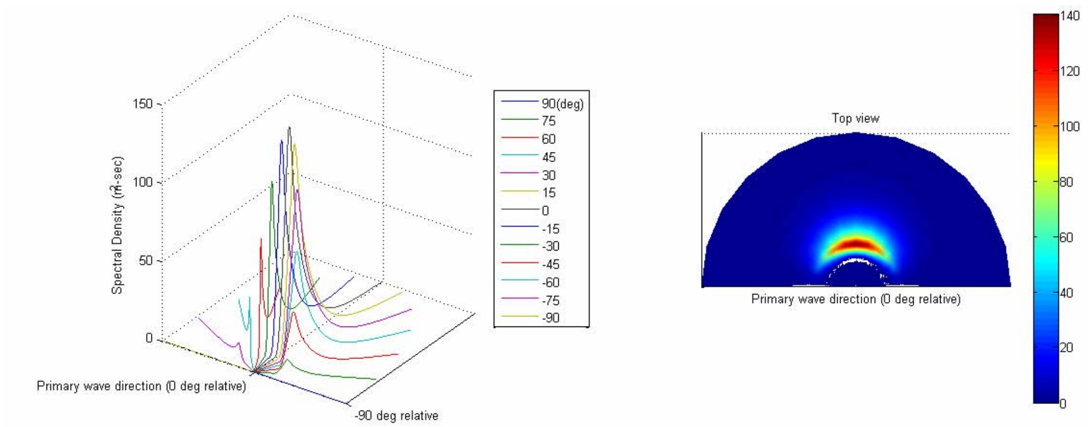

Figure 4.5: Directional Ochi hurricane spectra, 2 deg x 2 deg grid size, 50 yr return period, 90 degree spreading, m = 2, H_s = 20.01m, T_m = 14.14 sec (43^o N, 163^o E)

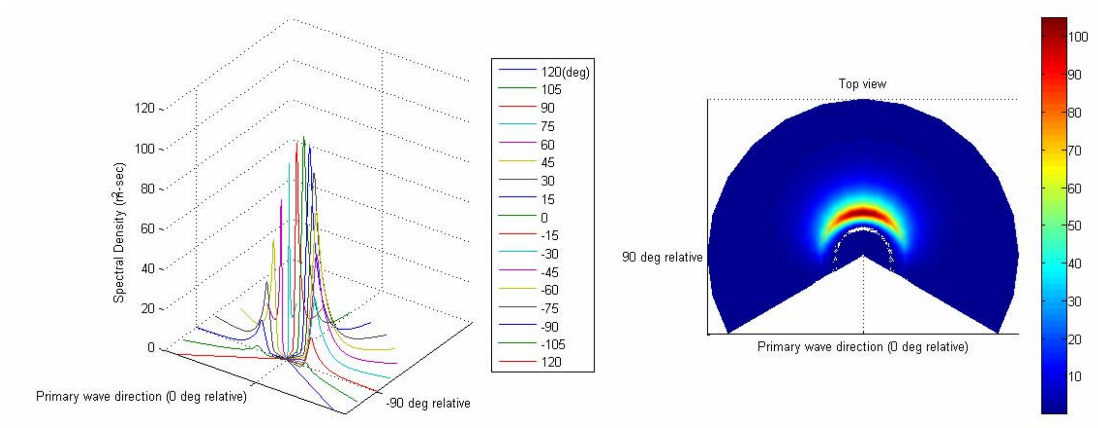

Figure 4.6: Directional Ochi hurricane spectra, 2 deg x 2 deg grid size, 50 yr return period, 120 degree spreading, m = 2, H_s = 20.01m, T_m = 14.14 sec (43^o N - 163^o E)

5 Discussion

5.1 Assumptions

In this section, some of the assumptions made for the statistical extreme data construction and validation are discussed.

5.1.1 Linear Theory

This thesis is based on the Stokes linear approximation. It is based on the theory that a wave system can be constructed using a linear superposition of a large number of simple Airy waves. These small amplitude equations are linear and individual components can be added to calculate the resultant wave elevation as shown in Equation (4.1-1).

$$\zeta = \zeta_1 + \zeta_2 + \zeta_3 + \ldots \zeta_n \tag{4.1-1}$$

Where:

$$\zeta = a \exp(kz)\cos(kx - \omega t - \phi) \tag{4.1-2}$$

Equation (4.1-2) is derived from the Stokes fifth order equation (Equation 4.1-3) by eliminating higher order terms.

$$\begin{aligned} k\eta(x,t) = {} & \left(\varepsilon - \frac{3}{8}\varepsilon^3 + \frac{422}{384}\varepsilon^5\right)\cos(kx - \omega t) + \left(\frac{1}{2}\varepsilon^2 + \frac{1}{3}\varepsilon^4\right)\cos 2(kx - \omega t) \\ & + \left(\frac{3}{8}\varepsilon^3 + \frac{297}{384}\varepsilon^5\right)\cos 3(kx - \omega t) + \frac{1}{3}\varepsilon^4 \cos 4(kx - \omega t) \\ & + \frac{125}{384}\varepsilon^5 \cos 5(kx - \omega t) + O(\varepsilon^6) \end{aligned} \tag{4.1-3}$$

Where:

a = wave amplitude (crest to mean sea level)

z = death below the surface where it is taken as negative

φ = a phase angle which can be chosen to be any value

k = the wave number = 2π/λ

ω = 2π x the frequency

c = the phase velocity = ω/k

λ = the wavelength

y = the elevation above mean water level

$\varepsilon = kH/2$

H = the crest-to-trough wave height

The linear assumption is used to estimate the crest-to-trough height in the classic and Battjes methods as discussed in Section 3.3.3, and Tucker and Pitt [35] provide the following explanation about the linear assumption. The second harmonic in a periodic wave, which is generated by the second-order terms in the non-linear equations (Equation 4.1-3), has no effect on the crest-to-trough height as long as it does not produce second crest. Therefore, the classic and Battjes methods ignore only the third and higher order terms, and this works generally well for deep water although with limitations.

A bulk of water-wave theory is based on linear waves, and it is only a good approximation for waves with gentle slopes, and they provide no useful insight into breaking waves. The core of one range of theoretical approaches using the linear wave approximation is the linear wave properties of superposition. This includes both surface elevation and energy density as it is demonstrated throughout this thesis. However, the linear theory has clear limitations, and they are discussed in Section 5.1.2.

5.1.2 Non-linear Effects

A quick observation of wave-to-wave interactions out in the open ocean when waves are steep reveals that these interactions are highly non-linear phenomena, and this is especially true for breaking waves. Breaking waves have high steepness ratios, and therefore, non-linear terms are no longer negligible. Furthermore, non-linear terms play an important part when considering air and wave particles interactions during breaking. This, in turn, effects calculations of wave velocity profile and consequent pressure distribution of a breaking wave significantly.

The importance of non-linear effects is studied by Marthinsen et al. [24], and the following is a summary of their findings. Real surface waves are irregular and skewed. And, due to non-linear effects, the crest height is greater than the trough depth as shown in Figure 5.1. This is confirmed by Longuet-Higgins [23] who showed that at infinite water depth, the skewness is always positive (i.e. crest height is always greater than trough depth). Typically, extreme crest height is estimated from a deterministic or regular Stokes wave profile with wave height and period related to extreme significant

wave height and corresponding wave period and compared to a numerical estimation based on non-linear effects. However, for extreme North Sea conditions, Marthinsen et al. [24] discovered that a numerical estimation based on non-linear, non-Gaussian wave crests is lower than that of the deterministic wave method. In general at deep water, the slowly-varying part of the second-order waves gives a "negative" contribution to the wave skewness. The study done by Marthinsen et al. [24] is very interesting because it shows how non-linear effects are affecting the skewness of waves both positively and negatively. Due to these counter-balancing effects, the linear theory actually provides acceptable results in estimating extreme wave heights in many non-breaking conditions, and it is further discussed in Section 5.2.

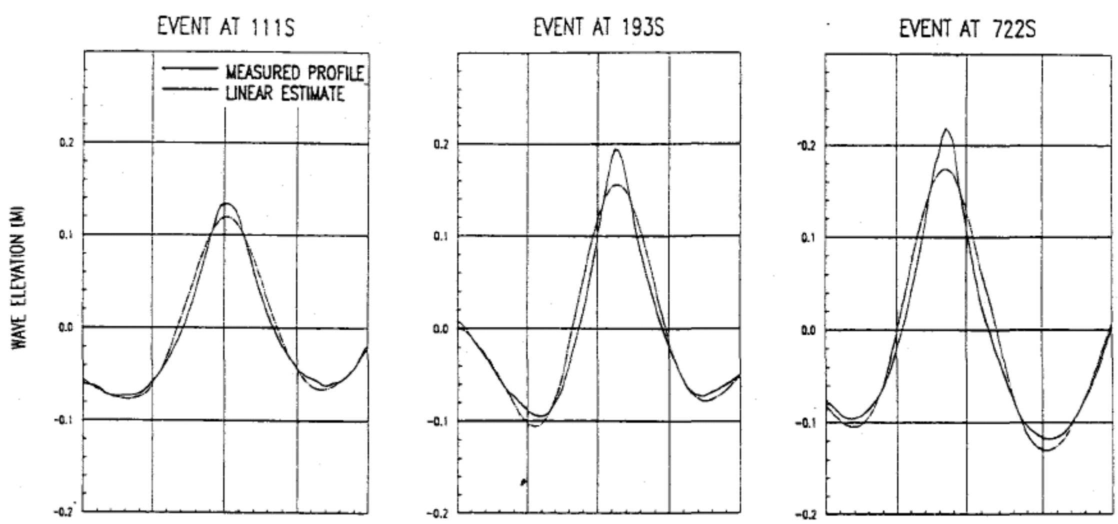

Figure 5.1: Time history samples of measured and reconstructed elevation for 3 events (different time periods as indicated by seconds, S) [33]

5.1.3 Rayleigh Distribution

It is usually found and assumed that the probability density function for wave heights is closely approximated by the Rayleigh distribution (Figure 5.2). Rayleigh distribution applies strictly to a narrow-band, random process, and all the analytical tools used in this thesis including the Ochi's short term order statistics used in Section 3.3.2 and the classic and Battjes extreme wave prediction methods in Section 3.3.3 assume the Rayleigh distribution. To be more precise, the classic and Battjes methods use a modified Rayleigh distribution based on empirical data for the statistical analysis. This is

a key assumption that many ocean wave statistical studies are based on, and Ochi [30] makes the following justifications for assuming stationary Gaussian (normal) process and hurricane-generated deep water waves to have narrow-band spectra.

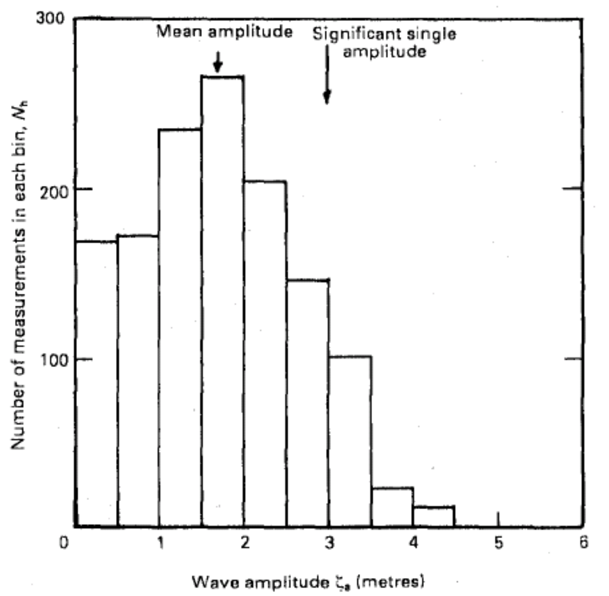

Figure 5.2: Typical histogram of amplitudes [22]

Ochi points out in [30] that if hurricane-generated deep water waves were narrow-band Gaussian, then the wave heights observed should follow the Rayleigh probability distribution. However, as discussed in Section 5.1.2, some of the recent studies have shown that the wave skewness exists and the magnitude of crest is greater than that of trough. Ochi contends that a lot of the wave height records that are reflected in the recent researches are done in finite water depths rather than in deep water, and this raises questions as to whether the results can be applied to deep water events. Furthermore, although most wave measurement records show that the magnitude of peaks is indeed greater than that of troughs, the departure from the Rayleigh distribution for wave heights is often of little concern. This point is further supported by the counteracting of non-linear effects discussed in Section 5.1.2 that actually brings the shapes of waves closer to that of linear waves. Therefore, Ochi argues that the hurricane-generated extreme waves can be considered a stationary Gaussian process and the Rayleigh probability distribution assumption is valid.

5.1.4 Subtleties

The following subtleties associated with extreme wave prediction are explained by Tucker and Pitt in [35] and summarized here.

What is an event?

Depending on how an event is defined, an outcome of any statistical analysis varies greatly. The classic method for estimating extreme wave height treats each 3-hr period as an independent event. This does not take into account that it is possible for the highest wave in 50 years to come from the second highest or even lower storms. In contrast, the Battjes method does take into account the possibility that the highest wave in 50 years cam come from other than the highest storm but counts each individual wave as an event where several individual waves from several storms exceeding the threshold count as several events. Other prediction methods that are not mentioned in thesis but exist consider each 3 hr period as a single event but also account for the possibility of the highest wave coming from storms other than the most severe one or treats each storm as a single event regardless of its duration.

Tucker and Pitt [35] point out that the classic and Battjes methods do not offer results that are significantly different from the other methods based on their event definitions. Furthermore, when considering waves, Tucker and Pitt [35] suggest considering the only the highest wave in one storm as it is the case with the results from the extrapolation model and wave simulation runs in this thesis. For the extreme wave height prediction using the Alves and Young's [2] extreme significant wave height data and the corresponding predicted values of extreme mean wave periods, each 3-hr period is treated as an independent event. For the wave simulation, both the periods of 3-hr and 3-day are considered. The 3-hr period is chosen because first, this is a standard measurement or observation period, and second, this will allow the comparison between the short term order statistics model in Section 3.3.2 and other prediction methods that are based on the 3-hr event period in Sections 3.3.3 and 3.4.1. The simulation data also includes the 3-day event period since it represents a reasonable estimation of some storm durations.

Return period

The return period of a stated value of variable is the average period of time between exceedence of that value [35]. For this thesis, the return periods of 50 and 100 years are considered.

Storm duration

So far it is assumed that all storms are rectangular meaning the significant waves rise suddenly to a value of H_s and drop to zero from this value as shown in Figure 5.3. In reality, this does not happen of course, and two different definitions of storm duration are being used. The D is the mean duration of an exceedence of a stated value of H_s. The second definition is the duration of the equivalent rectangular storm, and this value is not necessarily same as D. However, in practice, the difference in average values of high exceedence seems to be minimal [35]. For this thesis, the value of D corresponds to that of a rectangular storm.

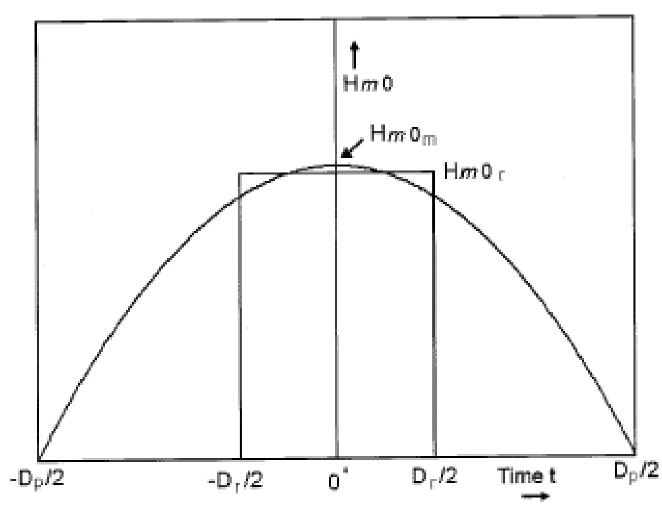

Figure 5.3: A 'parabolic' storm and its rectangular equivalent [35]

Storm Cluster

Storms have tendency to cluster, and it is common to experience sometimes storm periods where a number of storms follow one after another in quick succession. The effect of clustering has been studied extensively for the cases of flood but not for calculation of extreme waves. Nevertheless, for a time period less than or equal to one year, this seems to have minimal effects [35]. However, for a longer period, this is equivalent to considering several high individual waves from a single severe storm, and this effect gets mixed up with climate variability which is a subject of ongoing study that is not well understood yet. When a statistically stable population with no long-term correlation is used for extreme Hs prediction, the inter-annual variability of wave statistics is much greater than what is expected [35].

5.1.5 Most Probable Extreme Wave Height Data Comparison (North Pacific & North Atlantic)

The results from short term order statistics model show good agreement with the results from wave simulation, and this is shown in Table 5-1. For the data comparison, the short term order statistics results from the Ochi's hurricane-generated sea spectrum based on the extreme H_s based on FT1/IDM [2] and the predicted extreme T_m based on W2P with the 3-hr event period are used. The Pierson-Moskowitz spectrum based on the extreme H_s on FT1/IDM [2] with the 3-hr event period is used for wave simulation runs. Table 5-1 compares the entire data sets for the North Pacific and the North Atlantic, and it can be seen that these results are similar as the mean differences for both regions falling under ±10 %.

A couple of interesting observations can be made from Table 5-1. First, the most probable extreme wave heights from wave simulation runs are higher than those from the short term order statistics based extrapolation model. Second, the mean difference for North Atlantic is larger than North Pacific. Because the most probable extreme wave heights based on the extrapolation model have not been validated with measured data, whether the extrapolation model over or underestimates extreme wave heights cannot be determined at this point. And, as for the mean difference variation between the two regions, one possible explanation may lie with the mean wave period data [2] for the

North Atlantic since both the Pierson-Moskowitz and Ochi's hurricane-generated sea spectra use the same extreme H_s data from Alves and Young [2].

Table 5-1: Wave amplitude comparison (regional data of North Pacific and North Atlantic) of wave simulation vs. short term order statistics

		Mean difference	Standard Deviation
North Pacific	2 x 2, 50 yr	4.1%	3.7%
	2 x 2, 100 yr	4.2%	3.8%
North Atlantic	2 x 2, 50 yr	7.2%	3.7%
	2 x 2, 100 yr	7.2%	3.9%

5.2 Limiting Wave

In order to understand the effect of a single extreme wave that could stress one or more components of a marine structure beyond its strength limit or lead to capsizing of a vessel, the designer needs to know the wave height, h, period, T, and the direction of the extreme wave with a return period of 50 or 100 years. Especially, the wave period is crucial since drag forces depend on h/T and inertia forces on h/T^2 [35]. In this thesis, only the wave height and period have been considered. When the wave height is considered, there is a question of how high a wave can grow before it breaks. In this section, the limiting wave in deep water is briefly discussed.

In determining the break point of a wave, the parameter called steepness is often used. Steepness is defined as a ratio of crest-to-trough to wavelength. Lamp [19] and Michell [27] have shown that the highest progressive wave in deep water has a steepness of approximately 1/7 or 0.143. Cokelet [11] calculated this value to be 0.141 using a Stokes expansion to 100^{th} order. Interestingly, the mean value of steepness from the wave simulation using the Pierson-Moskowitz spectrum in waves that would be generated with a significant wave height of 20.01 m is 0.109, and this is much less than 0.141 or 0.143. This confirms that the wave simulation is based on the linear wave theory, which applies to waves with gentle slopes, but it also hints at something more fundamental.

In practice, the breaking limit in deep water is so high that it does not affect the estimation of extreme waves, and Tucker and Pitt [35] offer the following explanation. Based on the crest-to-trough height and zero-crossing period of the design wave as one of a regular periodic wave train as it is in this thesis, a typical site gives a steepness that is

below that of a breaking wave. Therefore, it is usually considered that the design wave height is not limited by breaking.[4] Actually, an extreme wave has a lower steepness than what's normally calculated, and this is due to the following reason [35]. In a sea with finite spectral width (i.e. narrow band), only partial correlation exists between the height of the crest and the depth of the adjacent troughs on either side. So, extreme crest is not normally accompanied by an extreme trough and vice versa. The estimated extreme crest-to-trough height in a typical storm relative to extreme significant wave height is approximately 10% less [35]. Table 5-2 compares the predicted extreme wave heights calculated by simply doubling the crest-to-mean heights from the wave simulation (Section 4.4) to the measured wave heights as measured from crest to trough from the same run. The predicted or calculated wave heights are indeed higher than the measured wave heights, and the values are fairly close to the above mentioned 10% range.

Table 5-2: Comparison of predicted wave height and measure wave height from the wave simulation (43^o N, 163^o E)

Grid size, Return Period	**$H_{extreme} = 2*\zeta_{extreme}$ (simulation, m)**	**$H_{extreme\_max}$ (simulation, m)**	**Difference**
2 x 2, 50 yr	35.66	32.06	11.2%
2 x 2,100 yr	37.52	33.09	13.4%

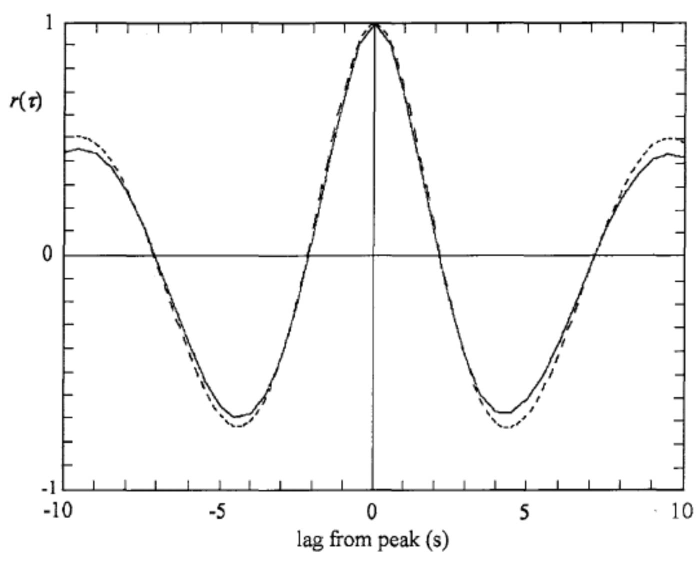

Figure 5.4: The continuous line is the normalized average time history of the wave with the highest crest in each of 1000 random simulations. The dahsed line is the theoretical autocorrelation function. The spectrum is JONSWAP with f_m = 0.1 Hz (modal frequency) [35]

[4] This assumption is valid for water height on a fixed (not floating) platform, but it is not acceptable for ships.

The extreme crest has the shape of the autocorrelation function as shown in Figure 5.4, which is the sum of the squares. Therefore, it has a shape nearer to that of a simple periodic wave than the average wave in the system. Based on these observations, the most probable wave height prediction results from this study that is primarily based on first order linear theory can be indeed considered valid to a certain extent. It should be noted, however, that this argument does not necessarily apply to the effects of non-linearity on other applications such as slope and vertical velocity/acceleration spectra mentioned in this thesis as they have not yet been validated. For seakeeping analysis, the wave slopes and fluid accelerations are most important, and they must be considered in addition to extreme wave heights as most of the highest waves will be so long that their only influence on a ship will be a slow gentle heave motion.

5.3 The Accuracy of Prediction of the Extreme Sea State

For this thesis, it is assumed that the wave climate is statistically stationary and that the sensors are accurate. Also, it is assumed that underlying long-term probability distribution function follows a known distribution function, and it can be extrapolated to a return period of 50 or 100 years. Still, the results based on these assumptions are as good as the assumptions themselves. In this section, the accuracy of prediction of zero-crossing wave period, T_z, and extreme wave heights is very briefly discussed.

Estimating the variability of T_z is difficult since the random fluctuations in different moments are correlated as Tucker and Pitt [35] points out. If the wave frequency band is confined to a single harmonic as it is the case for a narrow band wave, the fluctuations in the various moments would be 100% correlated, and the period would not vary measurably. When the bandwidth increases, however, the variability of significant wave height decreases, and that of period parameter increases. Typically, the coefficient of variance (standard deviation / mean) of T_z is less than that of significant wave height, and it is also true for other period parameters such as T_m estimated from spectral moments (Table 2-2) [35]. Lastly, T_z as well as H_s are subject to inherent random errors because they are derived from a finite sample of a random process.

Regarding extreme wave height, Ochi [31] points out that the chance of the predicted extreme value being exceeded is rather high with a theoretical value of 0.632 for a random process having narrow-band spectrum, and it is confirmed mathematically

by Tucker and Pitt [35]. This is a rather high possibility, and as Ochi [31] suggests the extreme value for a preassigned probability of being exceeded shown in Section 4.1 maybe more appropriate for ocean engineering design applications.

6 Conclusions

The main objective of this thesis is to construct a statistical database of amplitude and fluid velocity of large and rare waves in the ocean that can be used as a quick reference during the initial design stage of a marine structure or vehicle as well as in preparation for any future deep water studies regarding observation of extreme waves. Through short term order statistics based on extreme significant wave heights and corresponding mean wave periods from Alves and Young [2], statistics of wave amplitude and fluid velocity have been studied along with other environmental parameters.

The current development with Synthetic Aperture Radar or SAR provides a hope that better resolution of the time-varying sea surface will become available in the near future. Until then, however, no real source of wave period database corresponding to extreme waves exists, and this thesis has developed an extrapolation model that is identical to the one used for extreme significant wave height prediction [1] [35]. The mean wave period, T_m, extrapolation model used in this thesis is not perfect as it surely contains inherent errors and uncertainties. However, although this approach is based on linear theory, the results of most probable extreme wave heights based on the model are surprisingly close to other approximation methods that do not require wave period data.

A more accurate spectrum representing extreme sea conditions can be constructed based on two parameters of significant wave height and wave period than just one parameter of significant wave height or wind speed. Because of this, it is very encouraging that two parameter spectra used in this thesis can produce acceptable results, and it validates this approach to a certain extent. Once satellite measured wave periods become available, and the wave period prediction model in this thesis can be fully validated, this approach can provide other statistical data of large and rare waves that would not be available otherwise from extreme significant wave height data alone.

Statistical data of large and rare waves in the ocean can be valuable in determining design parameters of a marine structure or a ship and its operational limitations. In this thesis, various spectra corresponding to these potentially devastating extreme wave phenomena are constructed, and their potential applications have been

considered. Furthermore, spectral analysis allows prediction of the most probable extreme wave heights with a return period of 50 or 100 years, and these wave heights, also known as design wave heights, can be effectively used to optimize a marine design.

Until now, these extreme wave heights were measured by sparsely located in-situ instruments and sea going vessels that often provided inadequate environmental data. With the advent of satellite and radar altimeter technologies, however, a new kind of database has become available that is truly global in its coverage. Although satellite based data is not without limitations, it holds a great promise for future ocean environmental studies, and it is improved upon continuously.

Lastly, as part of this thesis, the assumptions based on linear theory and how they can affect the outcome of any statistical analysis are discussed. There exists sufficient knowledge of second order effects on wave generation, and it could be applied to a logical progression of the simulation approach in this thesis. However, because this greatly increases computation time, and the kinematics of deep sea spilling breakers are not yet fully understood for which substantial new research is required, the nonlinear effects are not included in this thesis. Because real ocean waves are non-linear, some of the assumptions based on linear theory have clear limitations. Nonetheless, linear theory can provide acceptable and sometimes excellent results when applied with correct assumptions. Most importantly, linear theory offers a powerful tool to study otherwise highly non-linear ocean phenomena that cannot be easily modeled and analyzed.

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Appendix A: North Pacific (21^o-45^o N, 161^o E-149^o W)

- Table A-1: Extreme significant wave heights predicted by Alves and Young
- Table A-2: Extreme wave heights predicted using FT1/IDM for significant wave height, FT1 for mean wave period and the Bretschneider spectrum for short term order statistics
- Table A-3: Extreme wave heights predicted using FT1/IDM for significant wave height, FT1 for mean wave period and the Ochi spectrum for short term order statistics
- Table A-4: Extreme wave heights predicted using FT1/IDM for significant wave height, W2P for mean wave period and the Bretschneider spectrum for short term order statistics
- Table A-5: Extreme wave heights predicted using FT1/IDM for significant wave height, W2P for mean wave period and the Ochi spectrum for short term order statistics
- Table A-6: Extreme wave heights predicted using FT1/IDM for significant wave height, average of FT1 & W2P for mean wave period and the Bretschneider spectrum for short term order statistics
- Table A-7: Extreme wave heights predicted using FT1/IDM for significant wave height, average of FT1 & W2P for mean wave period and the Ochi spectrum for short term order statistics
- Table A-8: Extreme wave amplitudes (RMS) predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 hrs) using the Pierson-Moskowitz spectrum
- Table A-9: Extreme wave amplitudes (RMS) predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table A-10: Extreme wave heights predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table A-11: Extreme wave zero upcrossing period predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table A-12: Mean minimum wave length of extreme wave predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table A-13: Extreme wave velocity (RMS) predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table A-14: Extreme wave acceleration (RMS) predicted using the Alves and Young's data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Table A-1: Extreme significant wave heights predicted by Alves and Young (Atlas of the Oceans)

Extreme Hs (in meters) prediction by I.R. Young & J.H.G.M. Alves using FT1 / IDM, 2 deg x 2 deg grid, 50 year return period

LONGITUDE

LATITUDE (N)	E										W															
	161	**163**	**165**	**167**	**169**	**171**	**173**	**175**	**177**	**179**	**179**	**177**	**175**	**173**	**171**	**169**	**167**	**165**	**163**	**161**	**159**	**157**	**155**	**153**	**151**	**149**
45	18.15	19.15	18.23	18.93	19.64	20.17	20.68	19.91	21.89	22.42	19.85	19	19.9	21.01	21.5	20.08	19.47	18.48	19.54	19.9	19.26	18.15	18.27	18.16	18.66	18.09
43	18.41	20.01	19.83	19.93	19.8	20.56	20.55	20.74	21.23	22.04	20.4	20.92	21.39	20.64	20.88	21.02	20.19	19.36	19.63	20.52	19.88	18.36	17.88	18.07	17.89	18.93
41	19.11	19.4	19.24	20.1	19.82	20.91	21.79	20.67	20.77	20.27	19.51	20.1	21.76	19.34	20.11	19.66	19.56	18.29	19.52	19.34	18.72	18.09	17.76	18.13	18.2	17.95
39	19.33	18.75	19.76	19.89	20.5	19.56	20.4	19.64	20.14	20.37	20.43	19.21	20.06	19.46	19.16	18.67	18.44	18.75	19.4	18.4	18.28	18.4	17.53	17.86	18.32	17.33
37	19.13	18.3	19.7	18.83	19.73	19.07	19.45	18.93	18.53	19.1	19.13	18.53	18.25	18.4	18.72	18.77	17.42	18.62	18.86	17.88	17.57	17.81	16.58	16.97	17.12	16.73
35	17.82	16.97	17.86	17.61	18.03	16.93	17.22	17.92	17.58	17.94	17.66	17.43	17.66	17.03	17.58	17.19	16.77	16.31	17.26	17.19	17.25	16.99	15.94	16.32	16.18	15.46
33	16.27	16.67	16.32	16.16	15.81	15.4	16.02	15.92	16.71	15.94	16.2	16.06	16.54	15.87	15.81	15.98	16.39	14.26	15.65	15.46	15.37	15.79	15.21	14.66	15.24	15.04
31	14.12	15.25	15.22	14.37	13.66	14.29	15.07	14.28	14.25	14.27	15.05	15.05	14.11	14.37	14.33	14.57	15.1	14.63	13.81	13.83	14.04	14.35	13.83	13.31	13.99	14.2
29	13.14	13.87	13.22	13.34	12.21	12.87	13.81	13.46	12.46	12.92	13.1	13.59	12.39	13.38	13.53	13.51	12.46	13.48	12.57	12.84	12.35	13.74	12.85	12.88	12.43	12.98
27	12.23	12.32	11.93	12.32	11.12	11.6	11.93	12.28	11.42	11.53	11.53	11.42	10.2	11.69	12.42	12.6	12.47	11.83	12.1	12.3	11.58	12.24	11.64	11.71	11.68	11.52
25	11.29	11.1	10.81	11.19	10.67	10.74	10.34	10.9	11.09	10.92	10.67	10.77	10.55	9.98	9.34	10.36	11.49	11.03	10.8	11.02	10.73	10.89	10.72	11.72	10.8	10.49
23	10.76	10.2	10.48	10.09	10.12	10.17	9.75	9.79	10.54	10.49	9.91	9.66	10.3	9.83	8.82	9.38	9.25	9.19	9.59	9.56	10.25	10.32	10.46	10.5	10.32	9.66
21	10.57	9.43	9.82	9.59	9.69	9.49	9.59	9.36	9.88	9.98	9.54	9.18	9.96	9.54	8.72	8.81	9.23	8.59	8.49	8.61	7.41	8.59	10	9.33	9.41	9.43

Extreme Hs (in meters) prediction by I.R. Young & J.H.G.M. Alves using FT1 / IDM, 2 deg x 2 deg grid, 100 year return period

LONGITUDE

LATITUDE (N)	E										W															
	161	**163**	**165**	**167**	**169**	**171**	**173**	**175**	**177**	**179**	**179**	**177**	**175**	**173**	**171**	**169**	**167**	**165**	**163**	**161**	**159**	**157**	**155**	**153**	**151**	**149**
45	19.07	20.13	19.15	19.89	20.64	21.19	21.73	20.92	23.01	23.57	20.85	19.96	20.91	22.08	22.61	21.1	20.45	19.4	20.53	20.91	20.23	19.06	19.18	19.07	19.6	19
43	19.34	21.03	20.84	20.94	20.81	21.61	21.6	21.8	22.31	23.16	21.44	21.99	22.48	21.68	21.94	22.1	21.22	20.34	20.63	21.56	20.89	19.28	18.78	18.97	18.79	19.89
41	20.08	20.39	20.21	21.12	20.82	21.97	22.91	21.73	21.82	21.3	20.49	21.13	22.87	20.32	21.14	20.66	20.55	19.21	20.52	20.31	19.66	18.99	18.65	19.04	19.12	18.85
39	20.31	19.7	20.76	20.9	21.54	20.55	21.44	20.63	21.16	21.42	21.47	20.19	21.08	20.45	20.13	19.61	19.37	19.7	20.39	19.33	19.21	19.33	18.42	18.77	19.25	18.21
37	20.1	19.22	20.7	19.78	20.74	20.04	20.44	19.89	19.47	20.07	20.11	19.47	19.18	19.33	19.67	19.72	18.3	19.57	19.82	18.79	18.46	18.71	17.41	17.83	17.99	17.58
35	18.72	17.82	18.76	18.49	18.94	17.78	18.09	18.83	18.47	18.85	18.56	18.31	18.56	17.89	18.47	18.06	17.62	17.13	18.14	18.06	18.13	17.85	16.75	17.15	17	16.24
33	17.09	17.51	17.14	16.97	16.6	16.17	16.82	16.72	17.56	16.74	17.02	16.87	17.38	16.67	16.61	16.79	17.22	14.97	16.44	16.24	16.14	16.59	15.98	15.39	16.01	15.8
31	14.82	16.02	15.98	15.09	14.34	15	15.83	14.99	14.97	14.98	15.81	15.8	14.81	15.09	15.05	15.3	15.86	15.36	14.5	14.52	14.74	15.07	14.52	13.97	14.69	14.91
29	13.79	14.56	13.87	14	12.81	13.51	14.5	14.13	13.07	13.56	13.74	14.26	13	14.05	14.21	14.18	13.07	14.14	13.19	13.46	12.95	14.43	13.48	13.52	13.04	13.62
27	12.84	12.92	12.51	12.92	11.65	12.16	12.51	12.88	11.97	12.08	12.09	11.98	10.68	12.26	13.03	13.21	13.08	12.39	12.69	12.89	12.13	12.84	12.2	12.27	12.25	12.07
25	11.84	11.63	11.32	11.73	11.18	11.25	10.83	11.42	11.62	11.44	11.17	11.28	11.05	10.45	9.77	10.85	12.04	11.55	11.31	11.54	11.24	11.4	11.23	12.28	11.31	10.98
23	11.28	10.69	10.97	10.57	10.59	10.65	10.2	10.25	11.04	10.98	10.37	10.1	10.78	10.29	9.22	9.81	9.68	9.61	10.03	10	10.73	10.8	10.95	10.99	10.8	10.1
21	11.07	9.87	10.28	10.04	10.14	9.93	10.03	9.79	10.34	10.44	9.98	9.6	10.42	9.98	9.11	9.21	9.65	8.98	8.86	9	7.73	8.99	10.47	9.75	9.83	9.85

Extreme Hs (in meters) prediction by I.R. Young & J.H.G.M. Alves using FT1 / IDM, 4 deg x 4 deg grid, 50 year return period

LONGITUDE

LATITUDE (N)	E										W															
	161	**163**	**165**	**167**	**169**	**171**	**173**	**175**	**177**	**179**	**179**	**177**	**175**	**173**	**171**	**169**	**167**	**165**	**163**	**161**	**159**	**157**	**155**	**153**	**151**	**149**
45	18.42	18.61	18.77	19.11	19.69	19.96	20.04	20.34	21.09	20.7	20.05	19.75	20.38	20.78	20.87	20.32	19.49	19.39	19.4	19.54	18.79	18.39	17.97	18.48	17.97	17.91
43	18.99	18.92	19.2	19.54	19.8	20.47	20.68	20.64	21.51	21.02	20.78	20.2	20.91	20.77	20.68	20.29	19.46	19.15	19.24	19.54	19.25	18.3	17.87	18.2	18.21	17.86
41	18.73	19.41	19.63	19.83	20.06	20.56	20.45	20.78	20.73	20.46	19.97	20.52	20.44	20.2	19.84	19.56	19.2	19.1	19.17	19.21	18.65	18.13	17.73	18.03	18.05	17.63
39	19.24	19.19	19.31	19.7	19.75	20.11	20.06	19.85	19.66	19.91	19.3	19.65	19.51	19.71	18.98	19.09	18.67	18.95	19.04	19.05	18.22	17.86	17.32	17.51	17.51	17.47
37	18.74	18.52	18.64	19.1	18.93	19.18	18.83	18.71	18.87	18.68	18.85	18.52	18.52	18.25	18.51	18.1	18.08	17.39	18.32	18.01	17.55	17.19	16.91	17.01	17.3	16.61
35	17.62	17.6	17.39	18	17.62	17.32	17.52	17.46	17.48	17.93	17.48	17.07	17.1	16.99	17.18	17.21	16.5	16.83	16.64	16.8	16.6	16.38	16.19	16.06	16.31	15.66
33	16.22	16.26	16.36	15.73	15.54	15.3	15.95	16.12	16.08	15.99	16.17	16.14	15.73	15.83	15.78	16.12	15.55	15.69	15.18	15.45	15.27	15.35	15.02	15.03	14.74	14.71
31	14.39	14.95	14.92	14.06	13.92	14.21	14.41	14.23	14.43	14.3	14.71	15.08	14.29	14.48	14.72	14.91	14.39	14.29	14.29	14.04	13.85	14.02	13.83	13.53	13.76	13.99
29	12.89	13.25	13.65	13.13	12.32	12.76	13.37	13.1	12.71	13.12	13.31	12.72	12.95	12.96	13.28	13.15	13.35	12.86	12.75	12.88	12.81	12.76	12.82	12.57	12.55	12.51
27	12.07	12.09	12.34	11.94	11.45	11.55	12.29	11.83	11.72	11.62	11.54	11.03	11.08	11.45	11.95	12.1	12.51	11.87	11.91	11.66	11.75	11.72	11.87	11.68	11.54	11.41
25	11.43	11.04	11.4	10.82	10.83	10.51	10.67	10.79	10.93	10.68	10.79	10.54	10.18	9.9	10.31	10.74	10.86	10.63	10.96	10.86	10.9	11.01	11.03	10.98	10.76	10.67
23	10.42	10.48	10.22	10.27	10.08	9.92	9.91	10.23	10.1	10.05	9.88	9.9	9.9	9.62	9.33	9.47	9.52	9.46	9.34	9.74	9.95	10.13	10.4	10.28	10.06	9.69
21	9.88	10	9.55	9.76	9.66	9.51	9.47	9.65	9.66	9.65	9.5	9.59	9.69	9.43	8.79	8.83	9.02	8.66	8.57	8.53	8.19	8.72	9.59	9.53	9.38	9.22

Extreme Hs (in meters) prediction by I.R. Young & J.H.G.M. Alves using FT1 / IDM, 4 deg x 4 deg grid, 100 year return period

LONGITUDE

LATITUDE (N)	E										W															
	161	**163**	**165**	**167**	**169**	**171**	**173**	**175**	**177**	**179**	**179**	**177**	**175**	**173**	**171**	**169**	**167**	**165**	**163**	**161**	**159**	**157**	**155**	**153**	**151**	**149**
45	19.36	19.56	19.73	20.08	20.69	20.98	21.06	21.37	22.16	21.75	21.06	20.75	21.42	21.83	21.93	21.35	20.48	20.37	20.38	20.53	19.73	19.31	18.87	19.41	18.87	18.81
43	19.96	19.88	20.17	20.53	20.8	21.51	21.73	21.69	22.6	22.08	21.84	21.23	21.97	21.83	21.74	21.32	20.44	20.11	20.21	20.52	20.23	19.21	18.76	19.11	19.13	18.76
41	19.68	20.4	20.62	20.84	21.07	21.61	21.49	21.84	21.78	21.5	20.98	21.56	21.48	21.23	20.84	20.55	20.18	20.06	20.14	20.18	19.59	19.04	18.62	18.94	18.97	18.52
39	20.22	20.16	20.28	20.7	20.75	21.13	21.08	20.85	20.66	20.92	20.28	20.65	20.51	20.71	19.94	20.06	19.61	19.92	20.01	20.02	19.14	18.76	18.19	18.4	18.4	18.35
37	19.68	19.46	19.57	20.06	19.89	20.15	19.79	19.66	19.83	19.63	19.8	19.47	19.46	19.18	19.44	19.02	19	18.27	19.25	18.93	18.45	18.06	17.76	17.87	18.18	17.45
35	18.51	18.49	18.26	18.91	18.51	18.19	18.4	18.35	18.36	18.84	18.37	17.93	17.97	17.85	18.05	18.08	17.33	17.69	17.48	17.65	17.45	17.21	17.01	16.87	17.14	16.45
33	17.03	17.07	17.18	16.52	16.32	16.06	16.75	16.93	16.89	16.79	16.99	16.96	16.52	16.63	16.57	16.93	16.33	16.48	15.95	16.23	16.03	16.12	15.78	15.79	15.48	15.45
31	15.1	15.7	15.66	14.76	14.61	14.92	15.13	14.94	15.15	15.02	15.44	15.84	15	15.21	15.46	15.66	15.11	15	15.01	14.74	14.53	14.72	14.52	14.2	14.44	14.69
29	13.53	13.9	14.33	13.78	12.92	13.38	14.03	13.75	13.33	13.77	13.97	13.35	13.59	13.6	13.94	13.79	14.01	13.49	13.37	13.52	13.44	13.39	13.45	13.19	13.17	13.12
27	12.66	12.68	12.94	12.52	12.01	12.11	12.9	12.4	12.29	12.18	12.1	11.55	11.61	12.01	12.54	12.69	13.11	12.45	12.49	12.22	12.31	12.28	12.45	12.25	12.1	11.95
25	11.99	11.58	11.95	11.34	11.35	11.01	11.17	11.3	11.46	11.18	11.31	11.04	10.66	10.36	10.8	11.25	11.37	11.13	11.48	11.37	11.42	11.54	11.55	11.5	11.26	11.17
23	10.91	10.98	10.71	10.75	10.55	10.39	10.37	10.71	10.57	10.52	10.34	10.36	10.36	10.07	9.76	9.91	9.95	9.9	9.77	10.18	10.41	10.6	10.88	10.75	10.53	10.13
21	10.34	10.47	10	10.21	10.11	9.95	9.91	10.1	10.1	10.09	9.94	10.03	10.14	9.86	9.18	9.23	9.43	9.04	8.96	8.91	8.55	9.12	10.04	9.96	9.8	9.63

Table A-2: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, FT1 for mean wave period and the Bretschneider spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, FT1 for Tm prediction, 2 deg x 2 deg grid, 50 year return period

		LONGITUDE																								
		E										W														
		161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	32.53	34.32	32.58	33.7	34.96	35.87	36.77	35.4	38.79	39.74	35.19	33.59	35.12	37.08	37.94	35.43	34.36	32.67	34.59	35.23	34.09	32.22	32.43	32.21	33.11	32.1
	43	32.9	35.76	35.37	35.51	35.28	36.59	36.4	36.74	37.51	38.97	36.07	36.95	37.75	36.43	36.85	37.06	35.6	34.1	34.58	36.15	35.16	32.48	31.64	31.92	31.66	33.5
	41	34.15	34.67	34.32	35.81	35.31	37.21	38.6	36.61	36.7	35.84	34.5	35.5	38.4	34.13	35.49	34.67	34.49	32.22	34.39	34.07	33.11	32.01	31.42	32.03	32.2	31.76
	39	34.45	33.41	35.08	35.34	36.42	34.66	36.05	34.71	35.55	35.98	36.09	33.89	35.37	34.31	33.82	32.94	32.53	33.09	34.23	32.47	32.38	32.58	31.04	31.6	32.32	30.57
	37	34	32.53	34.96	33.31	34.9	33.74	34.39	33.47	32.71	33.74	33.79	32.66	32.16	32.43	33.04	33.15	30.76	32.86	33.35	31.62	31.08	31.46	29.29	30.03	30.28	29.6
	35	31.67	30.16	31.69	31.15	31.89	29.95	30.45	31.69	31.04	31.69	31.2	30.73	31.12	30.01	31.03	30.36	29.61	28.79	30.52	30.4	30.51	30.01	28.16	28.88	28.62	27.35
	33	28.96	29.67	28.9	28.58	27.96	27.2	28.31	28.13	29.49	28.16	28.62	28.31	29.19	28.01	27.97	28.27	28.99	25.21	27.68	27.34	27.19	27.93	26.9	25.9	26.93	26.58
	31	25.06	27.07	26.95	25.44	24.19	25.31	26.61	25.21	25.18	25.19	26.57	26.63	24.98	25.44	25.38	25.8	26.74	25.81	24.43	24.47	24.85	25.35	24.44	23.56	24.74	25.11
	29	23.32	24.62	23.41	23.62	21.62	22.79	24.38	23.76	22.02	22.81	23.13	24.04	21.94	23.69	23.97	23.93	22.07	23.78	22.24	22.72	21.86	24.28	22.7	22.8	21.98	22.95
	27	21.76	21.92	21.2	21.84	19.71	20.56	21.1	21.72	20.22	20.44	20.44	20.23	18.04	20.67	21.95	22.25	22.02	20.92	21.38	21.73	20.44	21.59	20.53	20.66	20.65	20.36
	25	20.15	19.81	19.24	19.86	18.94	19.03	18.29	19.28	19.6	19.38	18.93	19.07	18.68	17.67	16.54	18.35	20.35	19.5	19.05	19.44	18.89	19.16	18.86	20.62	19.01	18.47
	23	19.2	18.2	18.66	17.91	17.96	18.02	17.25	17.32	18.63	18.61	17.58	17.11	18.24	17.41	15.62	16.61	16.38	16.25	16.92	16.87	18.04	18.16	18.41	18.48	18.17	17.01
	21	18.93	16.89	17.55	17.07	17.25	16.82	17	16.59	17.51	17.71	16.93	16.29	17.68	16.93	15.45	15.6	16.34	15.18	14.98	15.19	13.06	15.1	17.58	16.43	16.56	16.59

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, FT1 for Tm prediction, 2 deg x 2 deg grid, 100 year return period

		LONGITUDE																								
		E										W														
		161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	34.1	35.99	34.14	35.31	36.64	37.59	38.53	37.09	40.66	41.66	36.86	35.19	36.79	38.85	39.79	37.13	35.98	34.2	36.24	36.91	35.71	33.74	33.95	33.73	34.69	33.63
	43	34.47	37.48	37.07	37.21	36.98	38.35	38.15	38.51	39.31	40.83	37.8	38.73	39.56	38.15	38.61	38.85	37.31	35.72	36.24	37.87	36.84	34.02	33.13	33.42	33.16	35.1
	41	35.79	36.34	35.95	37.53	37	38.99	40.47	38.38	38.44	37.55	36.13	37.21	40.25	35.76	37.2	36.32	36.13	33.74	36.04	35.68	34.68	33.51	32.91	33.54	33.74	33.26
	39	36.1	35.01	36.75	37.03	38.16	36.32	37.78	36.36	37.25	37.73	37.82	35.52	37.06	35.95	35.43	34.5	34.07	34.67	35.87	34.01	33.93	34.13	32.52	33.12	33.86	32.03
	37	35.63	34.07	36.63	34.89	36.58	35.35	36.04	35.07	34.27	35.35	35.42	34.22	33.7	33.96	34.62	34.72	32.22	34.44	34.95	33.13	32.56	32.96	30.67	31.47	31.74	31.01
	35	33.18	31.59	33.2	32.61	33.41	31.37	31.9	33.2	32.51	33.2	32.69	32.18	32.61	31.43	32.51	31.8	31.03	30.15	31.99	31.84	31.98	31.44	29.5	30.27	29.99	28.65
	33	30.33	31.08	30.27	29.93	29.28	28.48	29.64	29.46	30.9	29.49	29.98	29.66	30.59	29.34	29.3	29.62	30.37	26.39	29	28.64	28.48	29.26	28.18	27.11	28.21	27.84
	31	26.23	28.36	28.22	26.64	25.32	26.49	27.87	26.39	26.38	26.37	27.83	27.87	26.15	26.64	26.58	27.02	28.01	27.02	25.58	25.62	26.01	26.55	25.58	24.66	25.91	26.29
	29	24.41	25.77	24.49	24.72	22.62	23.86	25.52	24.87	23.03	23.87	24.19	25.16	22.95	24.81	25.1	25.04	23.08	24.87	23.27	23.75	22.85	25.42	23.75	23.87	23	24.02
	27	22.78	22.92	22.17	22.84	20.59	21.49	22.06	22.71	21.14	21.36	21.38	21.17	18.83	21.62	22.96	23.26	23.03	21.85	22.36	22.71	21.35	22.58	21.45	21.58	21.59	21.27
	25	21.07	20.7	20.1	20.76	19.79	19.87	19.1	20.14	20.48	20.24	19.76	19.92	19.51	18.45	17.25	19.16	21.26	20.37	19.89	20.3	19.73	20	19.7	21.54	19.85	19.27
	23	20.08	19.03	19.48	18.71	18.74	18.81	17.99	18.08	19.46	19.43	18.35	17.84	19.04	18.17	16.28	17.33	17.1	16.94	17.64	17.59	18.83	18.95	19.21	19.28	18.96	17.73
	21	19.77	17.63	18.32	17.82	18	17.55	17.73	17.3	18.27	18.48	17.67	16.99	18.44	17.66	16.1	16.26	17.04	15.82	15.59	15.84	13.59	15.76	18.35	17.12	17.25	17.28

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, FT1 for Tm prediction, 4 deg x 4 deg grid, 50 year return period

		LONGITUDE																								
		E										W														
		161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	33.02	33.36	33.55	34.02	35.05	35.5	35.63	36.16	37.37	36.69	35.54	34.92	35.96	36.67	36.83	35.86	34.39	34.28	34.34	34.59	33.26	32.64	31.9	32.77	31.89	31.78
	43	33.94	33.81	34.24	34.81	35.28	36.42	36.63	36.56	38.01	37.17	36.74	35.68	36.9	36.66	36.49	35.78	34.31	33.73	33.9	34.42	34.05	32.38	31.62	32.15	32.22	31.6
	41	33.47	34.69	35.01	35.33	35.74	36.59	36.22	36.81	36.63	36.18	35.31	36.24	36.07	35.65	35.01	34.49	33.85	33.64	33.77	33.84	32.99	32.08	31.37	31.85	31.94	31.2
	39	34.29	34.2	34.28	35	35.09	35.64	35.45	35.08	34.71	35.17	34.09	34.67	34.4	34.75	33.5	33.68	32.94	33.44	33.6	33.61	32.27	31.62	30.67	30.98	30.89	30.82
	37	33.31	32.92	33.08	33.79	33.48	33.93	33.3	33.08	33.31	33	33.3	32.65	32.64	32.16	32.67	31.96	31.93	30.69	32.39	31.85	31.04	30.36	29.87	30.1	30.6	29.38
	35	31.32	31.28	30.86	31.84	31.17	30.64	30.98	30.87	30.86	31.67	30.88	30.09	30.13	29.94	30.33	30.39	29.14	29.7	29.42	29.71	29.36	28.93	28.6	28.42	28.85	27.7
	33	28.87	28.94	28.97	27.82	27.49	27.02	28.18	28.49	28.38	28.25	28.57	28.46	27.76	27.94	27.92	28.51	27.51	27.74	26.85	27.33	27.02	27.15	26.56	26.55	26.05	26
	31	25.54	26.54	26.42	24.9	24.65	25.16	25.44	25.12	25.5	25.25	25.97	26.68	25.3	25.64	26.07	26.4	25.48	25.21	25.28	24.84	24.51	24.77	24.44	23.95	24.33	24.74
	29	22.88	23.52	24.17	23.25	21.81	22.6	23.61	23.13	22.46	23.16	23.5	22.5	22.93	22.95	23.52	23.29	23.64	22.68	22.56	22.79	22.67	22.54	22.65	22.25	22.19	22.12
	27	21.47	21.51	21.93	21.17	20.3	20.47	21.73	20.92	20.76	20.6	20.46	19.54	19.59	20.25	21.12	21.37	22.09	20.99	21.05	20.6	20.74	20.67	20.93	20.61	20.4	20.17
	25	20.4	19.7	20.3	19.21	19.22	18.62	18.87	19.09	19.32	18.95	19.14	18.67	18.03	17.53	18.26	19.02	19.23	18.8	19.34	19.16	19.19	19.37	19.41	19.32	18.94	18.79
	23	18.6	18.7	18.19	18.23	17.89	17.58	17.53	18.09	17.85	17.83	17.53	17.53	17.53	17.04	16.52	16.77	16.86	16.73	16.48	17.18	17.52	17.82	18.3	18.09	17.71	17.06
	21	17.69	17.91	17.06	17.37	17.2	16.86	16.79	17.11	17.12	17.13	16.86	17.02	17.2	16.74	15.57	15.63	15.97	15.3	15.12	15.05	14.44	15.33	16.86	16.78	16.51	16.22

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, FT1 for Tm prediction, 4 deg x 4 deg grid, 100 year return period

		LONGITUDE																								
		E										W														
		161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	34.61	34.97	35.17	35.65	36.73	37.21	37.34	37.89	39.16	38.45	37.23	36.58	37.69	38.41	38.59	37.57	36.03	35.91	35.98	36.24	34.83	34.18	33.4	34.33	33.4	33.29
	43	35.58	35.43	35.88	36.48	36.96	38.17	38.38	38.31	39.82	38.93	38.51	37.39	38.66	38.42	38.25	37.48	35.94	35.32	35.5	36.04	35.68	33.89	33.1	33.66	33.76	33.1
	41	35.08	36.36	36.68	37.03	37.44	38.35	37.96	38.58	38.37	37.91	36.99	37.97	37.8	37.36	36.67	36.13	35.48	35.23	35.38	35.45	34.55	33.59	32.85	33.36	33.47	32.68
	39	35.94	35.83	35.9	36.68	36.77	37.34	37.15	36.74	36.37	36.85	35.72	36.33	36.06	36.41	35.1	35.29	34.5	35.06	35.2	35.22	33.81	33.12	32.12	32.47	32.36	32.28
	37	34.88	34.49	34.63	35.38	35.08	35.55	34.89	34.67	34.91	34.58	34.88	34.22	34.19	33.7	34.22	33.49	33.46	32.15	33.94	33.38	32.54	31.81	31.28	31.54	32.07	30.78
	35	32.81	32.77	32.31	33.35	32.65	32.09	32.44	32.36	32.32	33.19	32.36	31.52	31.58	31.36	31.77	31.84	30.52	31.13	30.82	31.12	30.78	30.31	29.96	29.77	30.24	29.02
	33	30.23	30.3	30.34	29.13	28.78	28.28	29.51	29.83	29.72	29.58	29.93	29.81	29.07	29.27	29.23	29.86	28.8	29.05	28.13	28.63	28.28	28.43	27.83	27.81	27.28	27.23
	31	26.73	27.79	27.65	26.06	25.79	26.35	26.63	26.3	26.69	26.44	27.18	27.95	26.49	26.86	27.31	27.66	26.68	26.38	26.48	26.01	25.64	25.93	25.58	25.07	25.46	25.91
	29	23.95	24.6	25.3	24.33	22.81	23.63	24.7	24.2	23.49	24.24	24.59	23.55	24	24.01	24.62	24.35	24.74	23.73	23.59	23.85	23.72	23.59	23.7	23.28	23.23	23.14
	27	22.46	22.5	22.93	22.13	21.23	21.4	22.75	21.86	21.7	21.54	21.4	20.41	20.47	21.18	22.1	22.35	23.09	21.95	22.01	21.53	21.67	21.59	21.89	21.55	21.33	21.06
	25	21.34	20.61	21.22	20.07	20.09	19.45	19.7	19.93	20.2	19.78	20.01	19.5	18.82	18.29	19.07	19.87	20.08	19.62	20.19	20	20.04	20.24	20.26	20.18	19.76	19.61
	23	19.42	19.54	19.01	19.03	18.67	18.36	18.29	18.89	18.63	18.61	18.3	18.3	18.29	17.78	17.23	17.5	17.57	17.46	17.19	17.91	18.27	18.6	19.09	18.86	18.48	17.78
	21	18.47	18.7	17.82	18.12	17.95	17.58	17.52	17.85	17.85	17.86	17.59	17.75	17.95	17.45	16.22	16.29	16.65	15.92	15.76	15.68	15.03	15.98	17.6	17.49	17.19	16.89

Table A-3: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, FT1 for mean wave period and the Ochi spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, FT1 for Tm prediction, 2 deg x 2 deg grid, 50 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	30.82	32.6	30.73	31.62	32.86	33.71	34.56	33.21	36.36	37.3	32.86	31.19	32.57	34.46	35.31	32.87	31.83	30.29	32.21	32.83	31.73	30.04	30.24	29.98	30.9	29.91
43	31.03	33.85	33.36	33.44	33.21	34.43	34	34.33	34.95	36.41	33.59	34.39	35.12	33.84	34.24	34.41	33	31.5	31.98	33.49	32.72	30.15	29.33	29.54	29.35	31.13
41	32.26	32.77	32.32	33.74	33.25	35.04	36.15	34.21	34.17	33.37	32.06	32.99	35.76	31.62	32.93	32.1	31.93	29.69	31.79	31.48	30.74	29.69	29.12	29.64	29.88	29.45
39	32.4	31.39	32.82	33.12	34.18	32.34	33.55	32.25	33.01	33.45	33.55	31.38	32.77	31.75	31.33	30.46	30.07	30.62	31.71	30.01	30.1	30.27	28.78	29.29	29.85	28.17
37	31.84	30.4	32.7	30.93	32.47	31.36	31.97	31.08	30.27	31.29	31.34	30.16	29.66	29.91	30.58	30.7	28.4	30.4	30.95	29.28	28.78	29.09	27	27.79	28.02	27.35
35	29.57	28.1	29.52	28.85	29.56	27.7	28.16	29.35	28.65	29.31	28.83	28.3	28.66	27.6	28.65	28.01	27.3	26.49	28.22	28.1	28.23	27.69	25.91	26.68	26.42	25.19
33	26.98	27.68	26.73	26.37	25.78	25	26.08	25.91	27.16	25.92	26.36	25.99	26.87	25.74	25.79	26.07	26.77	23.12	25.51	25.19	25.06	25.74	24.76	23.76	24.76	24.42
31	23.12	25.05	24.85	23.4	22.2	23.28	24.42	23.09	23.08	23.07	24.38	24.51	22.96	23.4	23.36	23.75	24.65	23.62	22.41	22.44	22.82	23.25	22.37	21.59	22.69	23.04
29	21.46	22.7	21.46	21.66	19.76	20.88	22.3	21.71	20.08	20.81	21.11	22.04	20.06	21.73	22	21.96	20.19	21.7	20.32	20.78	19.97	22.22	20.73	20.87	20.07	20.99
27	20.03	20.18	19.45	20	17.98	18.78	19.23	19.81	18.44	18.68	18.68	18.46	16.34	18.82	20.02	20.29	20.07	19.06	19.47	19.81	18.57	19.62	18.62	18.75	18.79	18.52
25	18.57	18.25	17.64	18.15	17.28	17.32	16.58	17.52	17.81	17.68	17.26	17.35	16.98	16.03	14.96	16.67	18.56	17.72	17.24	17.6	17.04	17.28	17	18.66	17.16	16.65
23	17.67	16.71	17.08	16.3	16.35	16.37	15.6	15.67	16.89	16.96	15.99	15.5	16.56	15.78	14.1	15.03	14.82	14.66	15.24	15.19	16.25	16.35	16.58	16.64	16.37	15.28
21	17.49	15.53	16.11	15.57	15.74	15.25	15.41	15.03	15.89	16.12	15.38	14.77	16.08	15.38	13.95	14.08	14.77	13.64	13.44	13.64	11.65	13.49	15.79	14.76	14.86	14.89

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, FT1 for Tm prediction, 2 deg x 2 deg grid, 100 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	32.23	34.11	32.13	33.06	34.36	35.24	36.13	34.73	38.03	39.02	34.34	32.59	34.04	36.03	36.94	34.36	33.26	31.63	33.68	34.33	33.16	31.39	31.59	31.33	32.29	31.26
43	32.44	35.41	34.89	34.97	34.74	36.01	35.56	35.9	36.54	38.06	35.12	35.96	36.72	35.36	35.79	35.99	34.5	32.92	33.43	35	34.21	31.5	30.65	30.85	30.67	32.55
41	33.74	34.28	33.79	35.28	34.76	36.64	37.81	35.78	35.7	34.88	33.5	34.5	37.38	33.05	34.44	33.55	33.36	31.02	33.24	32.89	32.12	31.01	30.43	30.97	31.23	30.78
39	33.88	32.82	34.31	34.63	35.74	33.8	35.08	33.7	34.5	35	35.08	32.81	34.26	33.2	32.75	31.82	31.42	32.01	33.15	31.36	31.47	31.64	30.09	30.63	31.2	29.45
37	33.28	31.77	34.18	32.32	33.96	32.78	33.42	32.49	31.64	32.71	32.77	31.52	31.01	31.26	31.97	32.09	29.69	31.79	32.37	30.62	30.09	30.4	28.21	29.05	29.3	28.6
35	30.9	29.36	30.85	30.13	30.89	28.94	29.43	30.69	29.95	30.64	30.15	29.57	29.97	28.84	29.94	29.28	28.54	27.68	29.52	29.38	29.53	28.95	27.09	27.9	27.62	26.34
33	28.2	28.93	27.93	27.55	26.92	26.11	27.23	27.06	28.39	27.08	27.56	27.16	28.09	26.9	26.97	27.26	27.99	24.15	26.66	26.33	26.18	26.91	25.88	24.82	25.88	25.53
31	24.15	26.18	25.96	24.45	23.19	24.31	25.51	24.11	24.12	24.09	25.48	25.6	23.98	24.45	24.41	24.82	25.77	24.67	23.41	23.45	23.84	24.29	23.37	22.56	23.71	24.08
29	22.4	23.71	22.4	22.62	20.62	21.8	23.29	22.67	20.95	21.72	22.02	23.01	20.94	22.7	23	22.93	21.07	22.64	21.22	21.67	20.84	23.22	21.63	21.8	20.95	21.92
27	20.92	21.06	20.3	20.87	18.74	19.59	20.06	20.67	19.23	19.47	19.49	19.27	17.02	19.64	20.9	21.16	20.94	19.86	20.32	20.65	19.35	20.47	19.42	19.55	19.61	19.31
25	19.39	19.03	18.38	18.93	18.01	18.05	17.28	18.25	18.56	18.43	17.98	18.08	17.7	16.7	15.57	17.37	19.35	18.46	17.96	18.34	17.76	18	17.72	19.44	17.87	17.33
23	18.43	17.43	17.79	16.99	17.03	17.05	16.24	16.32	17.6	17.66	16.65	16.12	17.25	16.43	14.66	15.64	15.43	15.25	15.86	15.81	16.92	17.01	17.26	17.33	17.04	15.89
21	18.24	16.18	16.79	16.22	16.39	15.87	16.04	15.64	16.55	16.78	16.01	15.37	16.74	16.01	14.5	14.64	15.37	14.19	13.95	14.18	12.09	14.04	16.44	15.34	15.44	15.47

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, FT1 for Tm prediction, 4 deg x 4 deg grid, 50 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	31.3	31.64	31.68	31.93	32.94	33.34	33.44	33.96	34.98	34.32	33.2	32.47	33.39	34.07	34.23	33.28	31.87	31.84	31.97	32.21	30.92	30.45	29.73	30.53	29.71	29.6
43	32.05	31.93	32.25	32.76	33.21	34.27	34.23	34.16	35.44	34.65	34.24	33.16	34.3	34.06	33.9	33.17	31.76	31.14	31.31	31.82	31.64	30.04	29.31	29.76	29.9	29.3
41	31.59	32.79	33.01	33.27	33.67	34.43	33.83	34.4	34.1	33.69	32.85	33.7	33.5	33.09	32.47	31.93	31.31	31.06	31.2	31.26	30.62	29.75	29.07	29.47	29.63	28.91
39	32.25	32.16	32.04	32.79	32.88	33.29	32.97	32.61	32.19	32.67	31.62	32.12	31.84	32.18	31.02	31.17	30.46	30.96	31.09	31.11	29.99	29.35	28.42	28.7	28.48	28.41
37	31.16	30.78	30.86	31.39	31.1	31.55	30.91	30.7	30.85	30.57	30.86	30.14	30.12	29.66	30.22	29.56	29.52	28.31	30.03	29.5	28.74	28.03	27.56	27.86	28.32	27.15
35	29.22	29.19	28.71	29.51	28.86	28.37	28.67	28.57	28.48	29.29	28.53	27.69	27.72	27.53	27.97	28.05	26.84	27.37	27.17	27.44	27.13	26.66	26.34	26.24	26.64	25.53
33	26.9	26.97	26.8	25.64	25.32	24.83	25.96	26.24	26.1	26.01	26.31	26.13	25.51	25.67	25.74	26.31	25.34	25.54	24.71	25.17	24.89	25	24.44	24.38	23.92	23.86
31	23.58	24.54	24.34	22.88	22.64	23.14	23.3	23	23.39	23.12	23.81	24.56	23.27	23.59	24.02	24.33	23.45	23.05	23.22	22.8	22.49	22.69	22.37	21.97	22.3	22.69
29	21.03	21.64	22.19	21.31	19.94	20.69	21.56	21.11	20.5	21.14	21.46	20.57	21	21.02	21.58	21.35	21.69	20.66	20.62	20.84	20.74	20.57	20.68	20.35	20.27	20.2
27	19.75	19.79	20.15	19.36	18.54	18.7	19.83	19.06	18.94	18.83	18.7	17.81	17.8	18.42	19.24	19.45	20.14	19.12	19.16	18.74	18.85	18.75	19	18.7	18.55	18.34
25	18.81	18.15	18.64	17.53	17.55	16.93	17.13	17.33	17.54	17.28	17.46	16.97	16.36	15.9	16.58	17.3	17.5	17.05	17.5	17.34	17.32	17.48	17.51	17.43	17.09	16.94
23	17.09	17.19	16.64	16.61	16.29	15.95	15.87	16.4	16.16	16.22	15.94	15.9	15.9	15.43	14.95	15.18	15.27	15.11	14.83	15.49	15.76	16.03	16.48	16.28	15.94	15.33
21	16.31	16.51	15.65	15.86	15.69	15.28	15.21	15.51	15.52	15.57	15.32	15.46	15.63	15.2	14.07	14.11	14.42	13.76	13.57	13.51	12.92	13.7	15.12	15.08	14.81	14.55

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, FT1 for Tm prediction, 4 deg x 4 deg grid, 100 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	32.75	33.1	33.14	33.39	34.45	34.87	34.97	35.51	36.56	35.88	34.7	33.94	34.91	35.6	35.78	34.79	33.31	33.28	33.42	33.68	32.3	31.82	31.06	31.91	31.04	30.94
43	33.53	33.39	33.72	34.25	34.72	35.84	35.78	35.71	37.04	36.21	35.8	34.67	35.85	35.61	35.45	34.67	33.18	32.53	32.72	33.24	33.09	31.38	30.61	31.09	31.25	30.62
41	33.04	34.3	34.51	34.79	35.19	36.01	35.37	35.97	35.64	35.22	34.34	35.23	35.02	34.59	33.93	33.36	32.74	32.45	32.6	32.67	32	31.09	30.38	30.8	30.98	30.21
39	33.73	33.62	33.48	34.29	34.37	34.8	34.46	34.07	33.65	34.14	33.06	33.58	33.3	33.64	32.42	32.58	31.82	32.38	32.51	32.53	31.35	30.67	29.7	30.01	29.77	29.69
37	32.56	32.18	32.24	32.8	32.51	32.97	32.32	32.09	32.25	31.96	32.25	31.52	31.48	31.01	31.58	30.9	30.87	29.6	31.4	30.85	30.07	29.3	28.8	29.12	29.62	28.38
35	30.54	30.51	29.99	30.84	30.16	29.64	29.96	29.87	29.76	30.62	29.83	28.93	28.98	28.78	29.23	29.32	28.05	28.62	28.4	28.69	28.38	27.87	27.53	27.43	27.86	26.69
33	28.1	28.17	28	26.79	26.45	25.93	27.11	27.42	27.27	27.17	27.5	27.31	26.65	26.83	26.9	27.5	26.48	26.69	25.84	26.31	26	26.12	25.55	25.49	24.99	24.94
31	24.62	25.64	25.42	23.89	23.64	24.17	24.34	24.02	24.43	24.16	24.86	25.67	24.3	24.66	25.1	25.43	24.5	24.07	24.27	23.82	23.48	23.7	23.37	22.94	23.29	23.71
29	21.96	22.59	23.18	22.25	20.81	21.58	22.5	22.04	21.38	22.07	22.41	21.49	21.93	21.95	22.54	22.28	22.65	21.56	21.52	21.77	21.66	21.48	21.58	21.25	21.16	21.08
27	20.62	20.65	21.02	20.2	19.34	19.5	20.71	19.87	19.76	19.64	19.51	18.55	18.56	19.23	20.08	20.3	20.99	19.96	19.99	19.54	19.65	19.55	19.83	19.52	19.36	19.11
25	19.64	18.94	19.45	18.28	18.3	17.65	17.84	18.06	18.3	18	18.21	17.68	17.05	16.55	17.28	18.03	18.23	17.76	18.24	18.06	18.05	18.22	18.24	18.16	17.79	17.64
23	17.8	17.92	17.36	17.29	16.96	16.62	16.52	17.08	16.82	16.9	16.6	16.55	16.55	16.07	15.56	15.81	15.88	15.73	15.43	16.1	16.4	16.69	17.15	16.94	16.59	15.94
21	16.99	17.21	16.31	16.51	16.34	15.9	15.84	16.15	16.15	16.19	15.94	16.09	16.28	15.81	14.62	14.67	15	14.29	14.12	14.03	13.42	14.25	15.74	15.68	15.39	15.11

Table A-4: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, W2P for mean wave period and the Bretschneider spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, W2P for Tm prediction, 2 deg x 2 deg grid, 50 year return period

LONGITUDE

	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	33.36	35.19	33.43	34.62	35.92	36.86	37.77	36.36	39.89	40.85	36.16	34.56	36.13	38.14	39.01	36.44	35.33	33.58	35.54	36.2	35.02	33.07	33.29	33.08	34.01	32.98
43	33.74	36.68	36.29	36.45	36.22	37.57	37.43	37.78	38.58	40.07	37.09	38.01	38.83	37.47	37.9	38.11	36.61	35.07	35.57	37.18	36.13	33.38	32.51	32.82	32.54	34.43
41	35.03	35.56	35.21	36.76	36.25	38.21	39.69	37.65	37.74	36.85	35.47	36.52	39.5	35.11	36.5	35.65	35.47	33.13	35.37	35.04	34.02	32.89	32.29	32.93	33.11	32.65
39	35.36	34.3	36.05	36.29	37.41	35.64	37.1	35.71	36.59	37.02	37.13	34.85	36.39	35.3	34.77	33.86	33.44	34.01	35.18	33.37	33.25	33.48	31.89	32.48	33.24	31.45
37	34.95	33.43	35.93	34.27	35.91	34.7	35.37	34.42	33.66	34.7	34.75	33.61	33.09	33.36	33.97	34.06	31.61	33.78	34.28	32.5	31.95	32.35	30.11	30.85	31.12	30.41
35	32.55	31	32.58	32.05	32.81	30.8	31.31	32.58	31.93	32.59	32.08	31.62	32.02	30.88	31.9	31.19	30.43	29.59	31.37	31.24	31.37	30.86	28.95	29.67	29.41	28.1
33	29.73	30.46	29.72	29.4	28.76	27.99	29.11	28.93	30.35	28.95	29.42	29.12	30.02	28.8	28.73	29.04	29.78	25.91	28.44	28.1	27.94	28.69	27.64	26.62	27.69	27.32
31	25.76	27.82	27.72	26.17	24.88	26.02	27.38	25.95	25.91	25.9	27.32	27.37	25.68	26.15	26.07	26.5	27.47	26.53	25.1	25.13	25.52	26.06	25.11	24.2	25.42	25.8
29	23.97	25.31	24.07	24.3	22.24	23.43	25.09	24.46	22.65	23.45	23.78	24.71	22.55	24.35	24.62	24.57	22.66	24.44	22.84	23.33	22.45	24.95	23.33	23.42	22.58	23.58
27	22.35	22.52	21.78	22.46	20.27	21.14	21.7	22.34	20.78	20.99	20.99	20.79	18.54	21.25	22.57	22.88	22.64	21.49	21.97	22.33	21.02	22.19	21.1	21.24	21.22	20.93
25	20.68	20.33	19.76	20.41	19.47	19.55	18.8	19.82	20.17	19.91	19.45	19.6	19.2	18.16	16.99	18.85	20.91	20.03	19.58	19.98	19.43	19.71	19.4	21.23	19.57	19.01
23	19.71	18.68	19.16	18.41	18.46	18.52	17.73	17.8	19.17	19.12	18.07	17.58	18.74	17.89	16.04	17.07	16.83	16.69	17.39	17.34	18.56	18.67	18.93	19.02	18.7	17.51
21	19.41	17.32	18.01	17.53	17.72	17.3	17.47	17.05	18	18.2	17.39	16.74	18.16	17.4	15.88	16.03	16.8	15.6	15.4	15.62	13.43	15.54	18.09	16.9	17.03	17.07

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, W2P for Tm prediction, 2 deg x 2 deg grid, 100 year return period

LONGITUDE

	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	35.02	36.97	35.09	36.35	37.72	38.69	39.65	38.17	41.89	42.9	37.95	36.27	37.93	40.05	40.99	38.25	37.08	35.22	37.31	38	36.75	34.7	34.92	34.71	35.7	34.61
43	35.42	38.52	38.11	38.27	38.03	39.46	39.31	39.68	40.51	42.07	38.95	39.91	40.77	39.32	39.78	40.03	38.44	36.81	37.34	39.03	37.93	35.02	34.11	34.43	34.15	36.15
41	36.78	37.34	36.96	38.6	38.05	40.12	41.7	39.55	39.62	38.69	37.22	38.35	41.48	36.85	38.33	37.42	37.23	34.76	37.14	36.76	35.7	34.5	33.88	34.55	34.75	34.26
39	37.13	36.01	37.84	38.1	39.27	37.41	38.95	37.48	38.41	38.89	38.98	36.6	38.2	37.06	36.5	35.53	35.1	35.7	36.94	35.02	34.91	35.14	33.48	34.1	34.9	33.01
37	36.69	35.08	37.72	35.97	37.71	36.43	37.13	36.13	35.34	36.43	36.5	35.29	34.74	35.01	35.66	35.75	33.18	35.48	35.99	34.12	33.54	33.95	31.59	32.39	32.68	31.93
35	34.17	32.53	34.19	33.62	34.44	32.32	32.86	34.21	33.52	34.21	33.69	33.18	33.62	32.4	33.49	32.74	31.94	31.05	32.94	32.8	32.94	32.39	30.4	31.15	30.88	29.5
33	31.2	31.97	31.19	30.85	30.17	29.36	30.54	30.36	31.86	30.38	30.88	30.56	31.51	30.23	30.16	30.48	31.26	27.18	29.85	29.49	29.31	30.12	29.01	27.92	29.06	28.68
31	27.01	29.2	29.07	27.46	26.09	27.28	28.74	27.21	27.19	27.17	28.67	28.71	26.93	27.44	27.36	27.81	28.82	27.83	26.33	26.36	26.77	27.34	26.34	25.38	26.67	27.07
29	25.14	26.54	25.23	25.47	23.31	24.57	26.32	25.65	23.74	24.59	24.92	25.91	23.64	25.55	25.83	25.77	23.75	25.61	23.95	24.44	23.52	26.18	24.45	24.56	23.67	24.72
27	23.45	23.59	22.82	23.53	21.21	22.14	22.73	23.41	21.76	21.98	21.99	21.8	19.4	22.27	23.65	23.96	23.73	22.49	23.02	23.38	21.99	23.26	22.1	22.23	22.23	21.9
25	21.67	21.28	20.68	21.38	20.38	20.46	19.68	20.75	21.11	20.84	20.35	20.51	20.09	19	17.75	19.72	21.89	20.96	20.49	20.91	20.33	20.61	20.3	22.22	20.48	19.88
23	20.64	19.56	20.04	19.27	19.3	19.37	18.53	18.62	20.06	20	18.89	18.37	19.6	18.71	16.75	17.83	17.6	17.44	18.17	18.12	19.41	19.52	19.79	19.88	19.55	18.29
21	20.32	18.11	18.83	18.34	18.52	18.08	18.26	17.82	18.82	19.02	18.18	17.49	18.99	18.19	16.58	16.75	17.55	16.29	16.06	16.31	14	16.25	18.92	17.65	17.78	17.81

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, W2P for Tm prediction, 4 deg x 4 deg grid, 50 year return period

LONGITUDE

	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	33.85	34.2	34.42	34.95	36.01	36.48	36.6	37.15	38.43	37.71	36.53	35.92	37	37.73	37.87	36.88	35.37	35.23	35.29	35.54	34.16	33.51	32.74	33.66	32.76	32.65
43	34.81	34.68	35.14	35.74	36.22	37.41	37.67	37.6	39.09	38.22	37.78	36.7	37.96	37.7	37.53	36.79	35.28	34.69	34.86	35.4	34.98	33.27	32.49	33.06	33.12	32.49
41	34.33	35.58	35.93	36.27	36.69	37.57	37.25	37.85	37.67	37.2	36.31	37.28	37.1	36.67	36.01	35.47	34.81	34.6	34.73	34.81	33.89	32.96	32.24	32.75	32.83	32.07
39	35.2	35.11	35.23	35.95	36.04	36.64	36.48	36.1	35.72	36.18	35.07	35.65	35.39	35.75	34.44	34.62	33.86	34.37	34.53	34.55	33.14	32.49	31.51	31.84	31.77	31.7
37	34.23	33.83	34	34.76	34.45	34.9	34.24	34.02	34.28	33.94	34.25	33.6	33.58	33.09	33.59	32.84	32.81	31.55	33.3	32.73	31.92	31.22	30.71	30.92	31.45	30.19
35	32.19	32.15	31.72	32.76	32.07	31.51	31.86	31.75	31.75	32.57	31.76	30.97	31	30.8	31.18	31.23	29.94	30.54	30.24	30.53	30.19	29.75	29.41	29.2	29.65	28.47
33	29.64	29.71	29.8	28.62	28.27	27.81	28.99	29.29	29.2	29.04	29.37	29.27	28.55	28.73	28.68	29.29	28.26	28.51	27.59	28.08	27.76	27.89	27.29	27.3	26.78	26.73
31	26.25	27.28	27.17	25.61	25.35	25.87	26.18	25.86	26.23	25.96	26.7	27.42	26	26.35	26.78	27.12	26.17	25.91	25.97	25.51	25.17	25.46	25.11	24.6	25	25.42
29	23.52	24.17	24.86	23.91	22.44	23.23	24.29	23.8	23.11	23.82	24.16	23.13	23.57	23.58	24.16	23.92	24.28	23.32	23.17	23.41	23.28	23.17	23.28	22.85	22.8	22.73
27	22.06	22.1	22.53	21.76	20.87	21.05	22.35	21.52	21.33	21.16	21.01	20.08	20.14	20.82	21.71	21.97	22.71	21.57	21.63	21.17	21.32	21.25	21.52	21.18	20.96	20.73
25	20.93	20.22	20.84	19.74	19.76	19.14	19.4	19.62	19.88	19.47	19.67	19.19	18.52	18.01	18.75	19.54	19.76	19.31	19.87	19.69	19.74	19.92	19.96	19.89	19.5	19.34
23	19.08	19.19	18.68	18.74	18.39	18.06	18.02	18.6	18.37	18.32	18.01	18.02	18.01	17.5	16.97	17.23	17.32	17.18	16.94	17.66	18.02	18.33	18.82	18.62	18.23	17.56
21	18.14	18.37	17.51	17.85	17.66	17.34	17.25	17.58	17.6	17.59	17.32	17.49	17.67	17.2	16.01	16.07	16.42	15.72	15.55	15.47	14.85	15.77	17.35	17.27	16.98	16.69

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, W2P for Tm prediction, 4 deg x 4 deg grid, 100 year return period

LONGITUDE

	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	35.55	35.92	36.15	36.69	37.81	38.31	38.43	38.99	40.34	39.59	38.34	37.71	38.85	39.6	39.75	38.71	37.13	36.98	37.04	37.31	35.84	35.15	34.35	35.32	34.37	34.26
43	36.56	36.41	36.89	37.52	38.01	39.28	39.55	39.48	41.03	40.11	39.67	38.53	39.84	39.59	39.42	38.62	37.03	36.39	36.58	37.14	36.73	34.9	34.08	34.68	34.77	34.1
41	36.04	37.36	37.71	38.09	38.51	39.46	39.11	39.75	39.54	39.06	38.11	39.13	38.96	38.5	37.79	37.23	36.56	36.3	36.46	36.53	35.57	34.59	33.82	34.37	34.48	33.66
39	36.96	36.85	36.97	37.74	37.83	38.47	38.3	37.88	37.5	37.98	36.82	37.43	37.17	37.53	36.15	36.35	35.53	36.09	36.25	36.27	34.78	34.1	33.07	33.43	33.36	33.27
37	35.92	35.52	35.67	36.48	36.17	36.63	35.95	35.72	35.99	35.63	35.94	35.29	35.25	34.74	35.25	34.48	34.45	33.12	34.96	34.38	33.52	32.77	32.23	32.46	33.02	31.69
35	33.79	33.75	33.28	34.38	33.66	33.07	33.43	33.34	33.32	34.2	33.34	32.5	32.55	32.33	32.73	32.78	31.42	32.07	31.74	32.05	31.71	31.23	30.87	30.64	31.13	29.88
33	31.09	31.17	31.26	30.03	29.66	29.16	30.41	30.74	30.65	30.47	30.83	30.73	29.95	30.15	30.09	30.74	29.65	29.92	28.96	29.47	29.11	29.26	28.65	28.65	28.1	28.05
31	27.53	28.62	28.49	26.86	26.58	27.14	27.46	27.12	27.52	27.24	28	28.78	27.27	27.65	28.1	28.46	27.46	27.17	27.25	26.76	26.39	26.7	26.34	25.79	26.21	26.67
29	24.66	25.34	26.07	25.07	23.51	24.34	25.47	24.96	24.21	24.97	25.34	24.25	24.71	24.73	25.34	25.06	25.46	24.44	24.28	24.55	24.41	24.29	24.4	23.96	23.91	23.82
27	23.12	23.15	23.61	22.8	21.87	22.05	23.44	22.53	22.34	22.16	22.01	21.01	21.09	21.81	22.76	23.02	23.78	22.6	22.66	22.17	22.32	22.24	22.55	22.19	21.96	21.69
25	21.94	21.19	21.83	20.67	20.69	20.03	20.29	20.53	20.82	20.36	20.6	20.08	19.38	18.83	19.63	20.45	20.67	20.19	20.8	20.6	20.66	20.86	20.88	20.81	20.39	20.22
23	19.97	20.09	19.56	19.59	19.23	18.9	18.84	19.46	19.2	19.16	18.83	18.84	18.83	18.31	17.74	18.01	18.09	17.96	17.7	18.44	18.83	19.16	19.67	19.45	19.07	18.34
21	18.98	19.21	18.32	18.65	18.47	18.12	18.04	18.39	18.38	18.38	18.11	18.28	18.48	17.97	16.71	16.78	17.15	16.4	16.24	16.15	15.48	16.48	18.14	18.03	17.72	17.41

Table A-5: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, W2P for mean wave period and the Ochi spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, W2P for Tm prediction, 2 deg x 2 deg grid, 50 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	33.13	35.05	33.06	34.12	35.47	36.39	37.28	35.82	39.31	40.29	35.45	33.69	35.18	37.25	38.1	35.47	34.34	32.63	34.71	35.38	34.14	32.28	32.5	32.27	33.28	32.21
43	33.36	36.41	35.9	36.03	35.78	37.13	36.75	37.11	37.76	39.33	36.27	37.15	37.94	36.54	36.97	37.12	35.59	33.96	34.48	36.12	35.25	32.47	31.58	31.84	31.64	33.57
41	34.69	35.25	34.78	36.35	35.82	37.8	39.08	36.98	36.9	36.02	34.61	35.62	38.63	34.13	35.54	34.61	34.42	31.99	34.28	33.95	33.09	31.96	31.35	31.95	32.22	31.75
39	34.91	33.81	35.43	35.69	36.85	34.92	36.28	34.86	35.7	36.15	36.27	33.84	35.39	34.28	33.77	32.8	32.38	32.95	34.14	32.3	32.35	32.6	30.99	31.55	32.21	30.38
37	34.38	32.82	35.29	33.44	35.12	33.86	34.5	33.54	32.7	33.77	33.82	32.57	32	32.28	32.95	33.04	30.55	32.75	33.36	31.54	31.02	31.35	29.09	29.88	30.16	29.44
35	31.91	30.32	31.84	31.17	31.95	29.88	30.37	31.66	30.94	31.62	31.1	30.54	30.92	29.76	30.85	30.13	29.36	28.51	30.4	30.27	30.43	29.84	27.91	28.68	28.42	27.1
33	29.03	29.78	28.84	28.46	27.81	26.98	28.1	27.92	29.32	27.91	28.39	28.01	28.95	27.72	27.73	28.02	28.78	24.87	27.43	27.08	26.93	27.67	26.6	25.56	26.65	26.29
31	24.9	27	26.79	25.23	23.93	25.06	26.35	24.9	24.89	24.82	26.24	26.37	24.7	25.17	25.09	25.51	26.48	25.39	24.06	24.09	24.49	24.98	24.04	23.17	24.37	24.75
29	23.1	24.44	23.11	23.34	21.28	22.46	24.05	23.41	21.62	22.37	22.69	23.7	21.55	23.36	23.63	23.57	21.66	23.31	21.8	22.29	21.41	23.87	22.26	22.39	21.53	22.53
27	21.53	21.7	20.92	21.53	19.34	20.19	20.69	21.33	19.8	20.02	20.02	19.83	17.54	20.23	21.52	21.8	21.56	20.45	20.9	21.26	19.93	21.06	19.98	20.12	20.16	19.88
25	19.92	19.57	18.94	19.51	18.57	18.59	17.81	18.82	19.16	18.98	18.53	18.63	18.22	17.19	16.02	17.87	19.91	18.98	18.49	18.89	18.29	18.55	18.24	20.07	18.47	17.91
23	18.94	17.91	18.33	17.51	17.57	17.56	16.75	16.82	18.17	18.2	17.15	16.63	17.76	16.92	15.09	16.11	15.87	15.69	16.33	16.28	17.44	17.53	17.78	17.89	17.61	16.44
21	18.74	16.63	17.27	16.71	16.89	16.39	16.55	16.13	17.07	17.28	16.49	15.85	17.26	16.5	14.97	15.1	15.85	14.61	14.4	14.61	12.47	14.47	16.95	15.84	15.94	15.98

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, W2P for Tm prediction, 2 deg x 2 deg grid, 100 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	34.82	36.86	34.74	35.85	37.28	38.24	39.17	37.64	41.31	42.36	37.24	35.39	36.96	39.13	40.05	37.26	36.06	34.25	36.47	37.17	35.86	33.89	34.12	33.88	34.96	33.83
43	35.05	38.28	37.74	37.86	37.61	39.04	38.63	39	39.67	41.33	38.11	39.04	39.86	38.37	38.84	39.02	37.39	35.66	36.22	37.94	37.04	34.09	33.16	33.42	33.23	35.27
41	36.46	37.05	36.54	38.2	37.63	39.72	41.09	38.87	38.76	37.85	36.34	37.44	40.59	35.85	37.35	36.36	36.15	33.59	36.02	35.63	34.75	33.55	32.92	33.55	33.84	33.34
39	36.68	35.52	37.23	37.51	38.71	36.69	38.12	36.61	37.5	38.01	38.11	35.55	37.18	36.02	35.47	34.44	34	34.61	35.87	33.92	33.99	34.25	32.56	33.16	33.83	31.92
37	36.13	34.47	37.08	35.12	36.91	35.57	36.25	35.23	34.35	35.47	35.55	34.21	33.62	33.9	34.62	34.7	32.09	34.42	35.06	33.15	32.59	32.93	30.54	31.4	31.69	30.93
35	33.52	31.83	33.44	32.72	33.55	31.38	31.89	33.26	32.5	33.21	32.68	32.08	32.48	31.25	32.41	31.65	30.84	29.93	31.95	31.8	31.98	31.35	29.33	30.14	29.86	28.46
33	30.49	31.28	30.28	29.87	29.19	28.31	29.49	29.31	30.8	29.3	29.82	29.41	30.41	29.11	29.13	29.44	30.23	26.1	28.81	28.45	28.28	29.07	27.95	26.83	27.99	27.61
31	26.13	28.35	28.12	26.49	25.11	26.3	27.67	26.13	26.14	26.04	27.56	27.68	25.92	26.43	26.35	26.79	27.81	26.65	25.25	25.29	25.7	26.23	25.23	24.32	25.58	25.98
29	24.23	25.65	24.24	24.49	22.31	23.57	25.24	24.56	22.67	23.47	23.79	24.86	22.61	24.53	24.81	24.74	22.71	24.44	22.87	23.36	22.45	25.07	23.34	23.5	22.58	23.63
27	22.6	22.75	21.93	22.57	20.25	21.16	21.69	22.36	20.74	20.97	20.99	20.8	18.36	21.21	22.57	22.85	22.61	21.41	21.91	22.27	20.87	22.08	20.93	21.08	21.14	20.82
25	20.89	20.5	19.82	20.45	19.45	19.46	18.64	19.7	20.07	19.88	19.39	19.51	19.07	17.99	16.75	18.71	20.86	19.87	19.35	19.77	19.15	19.4	19.1	21.01	19.32	18.74
23	19.86	18.77	19.18	18.34	18.37	18.38	17.51	17.6	19.02	19.05	17.94	17.38	18.58	17.7	15.77	16.84	16.6	16.4	17.07	17.02	18.24	18.33	18.6	18.71	18.42	17.17
21	19.63	17.4	18.07	17.49	17.67	17.14	17.3	16.86	17.85	18.07	17.24	16.57	18.05	17.26	15.63	15.77	16.56	15.26	15.01	15.26	13	15.13	17.74	16.53	16.63	16.67

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, W2P for Tm prediction, 4 deg x 4 deg grid, 50 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	33.65	34.01	34.09	34.46	35.56	35.99	36.06	36.63	37.8	37.05	35.83	35.09	36.07	36.82	36.92	35.92	34.38	34.32	34.45	34.71	33.27	32.72	31.94	32.86	31.99	31.87
43	34.46	34.33	34.71	35.29	35.78	36.96	36.99	36.92	38.28	37.42	36.98	35.81	37.04	36.78	36.6	35.77	34.24	33.57	33.76	34.31	34.08	32.35	31.56	32.08	32.24	31.59
41	33.97	35.26	35.52	35.84	36.27	37.13	36.56	37.18	36.83	36.38	35.46	36.41	36.17	35.72	35.04	34.42	33.76	33.48	33.63	33.71	32.96	32.04	31.3	31.77	31.94	31.16
39	34.74	34.64	34.59	35.34	35.43	35.95	35.64	35.25	34.81	35.3	34.16	34.65	34.37	34.74	33.44	33.57	32.8	33.32	33.47	33.49	32.23	31.6	30.6	30.91	30.71	30.64
37	33.65	33.23	33.3	33.94	33.63	34.06	33.35	33.13	33.33	32.99	33.3	32.55	32.5	32	32.57	31.8	31.77	30.49	32.36	31.79	30.99	30.21	29.7	29.96	30.49	29.22
35	31.54	31.5	30.96	31.89	31.19	30.61	30.92	30.81	30.76	31.6	30.77	29.88	29.89	29.69	30.12	30.17	28.86	29.46	29.25	29.55	29.23	28.72	28.37	28.21	28.66	27.47
33	28.93	29.01	28.91	27.66	27.31	26.79	27.97	28.29	28.16	28	28.33	28.15	27.47	27.65	27.67	28.28	27.23	27.49	26.57	27.06	26.75	26.86	26.26	26.24	25.74	25.68
31	25.4	26.44	26.24	24.66	24.41	24.92	25.14	24.81	25.22	24.87	25.62	26.42	25.03	25.38	25.81	26.13	25.18	24.78	24.93	24.48	24.14	24.38	24.04	23.57	23.95	24.37
29	22.64	23.3	23.9	22.96	21.48	22.26	23.24	22.75	22.08	22.73	23.08	22.11	22.58	22.59	23.17	22.91	23.28	22.19	22.13	22.36	22.24	22.09	22.2	21.83	21.75	21.68
27	21.23	21.27	21.68	20.83	19.94	20.1	21.35	20.51	20.34	20.19	20.04	19.12	19.13	19.8	20.67	20.9	21.64	20.52	20.56	20.11	20.24	20.13	20.4	20.07	19.91	19.68
25	20.18	19.46	20.02	18.84	18.86	18.17	18.4	18.62	18.87	18.55	18.75	18.22	17.55	17.04	17.76	18.55	18.77	18.26	18.78	18.6	18.6	18.76	18.8	18.75	18.39	18.23
23	18.32	18.43	17.86	17.84	17.49	17.11	17.03	17.61	17.38	17.41	17.1	17.06	17.04	16.54	16	16.27	16.36	16.17	15.89	16.6	16.91	17.2	17.68	17.5	17.15	16.49
21	17.46	17.68	16.77	17.02	16.84	16.42	16.33	16.66	16.67	16.68	16.41	16.59	16.77	16.3	15.09	15.13	15.47	14.74	14.54	14.47	13.84	14.7	16.23	16.19	15.89	15.6

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, W2P for Tm prediction, 4 deg x 4 deg grid, 100 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	35.38	35.76	35.85	36.21	37.37	37.84	37.9	38.49	39.71	38.93	37.63	36.86	37.9	38.67	38.79	37.72	36.11	36.05	36.19	36.47	34.93	34.36	33.54	34.52	33.59	33.48
43	36.23	36.08	36.47	37.08	37.59	38.85	38.87	38.79	40.21	39.3	38.86	37.63	38.91	38.65	38.46	37.57	35.95	35.24	35.45	36.02	35.81	33.96	33.12	33.68	33.86	33.17
41	35.7	37.07	37.32	37.67	38.11	39.04	38.42	39.08	38.68	38.22	37.25	38.24	38	37.54	36.79	36.15	35.47	35.15	35.32	35.39	34.62	33.64	32.86	33.37	33.56	32.73
39	36.51	36.4	36.32	37.13	37.22	37.78	37.45	37.02	36.57	37.08	35.89	36.4	36.13	36.5	35.12	35.27	34.44	35.02	35.17	35.19	33.86	33.19	32.13	32.48	32.27	32.18
37	35.33	34.92	34.96	35.64	35.32	35.78	35.04	34.8	35.01	34.66	34.97	34.21	34.13	33.62	34.19	33.41	33.37	32.02	34	33.41	32.58	31.73	31.18	31.47	32.04	30.69
35	33.13	33.09	32.51	33.5	32.76	32.14	32.47	32.37	32.3	33.2	32.33	31.38	31.4	31.18	31.64	31.68	30.31	30.96	30.73	31.04	30.73	30.17	29.8	29.63	30.12	28.85
33	30.38	30.45	30.35	29.04	28.67	28.11	29.37	29.7	29.57	29.39	29.76	29.57	28.84	29.04	29.05	29.7	28.6	28.87	27.91	28.43	28.07	28.2	27.58	27.56	27.02	26.97
31	26.65	27.76	27.53	25.88	25.61	26.15	26.39	26.04	26.47	26.12	26.88	27.75	26.27	26.65	27.1	27.45	26.44	26	26.18	25.69	25.32	25.59	25.23	24.74	25.13	25.58
29	23.75	24.43	25.09	24.09	22.52	23.33	24.38	23.87	23.15	23.85	24.21	23.2	23.69	23.71	24.32	24.02	24.42	23.27	23.2	23.47	23.33	23.18	23.29	22.9	22.82	22.73
27	22.27	22.31	22.72	21.83	20.9	21.07	22.4	21.49	21.32	21.15	21.01	20.02	20.04	20.76	21.68	21.91	22.66	21.52	21.55	21.07	21.19	21.08	21.38	21.04	20.87	20.6
25	21.17	20.41	20.98	19.74	19.76	19.03	19.25	19.49	19.78	19.41	19.65	19.07	18.37	17.83	18.6	19.43	19.64	19.11	19.66	19.46	19.47	19.65	19.67	19.62	19.23	19.07
23	19.18	19.3	18.71	18.66	18.3	17.91	17.81	18.42	18.17	18.21	17.89	17.85	17.83	17.31	16.73	17.02	17.09	16.91	16.61	17.34	17.68	17.98	18.48	18.29	17.93	17.22
21	18.27	18.51	17.56	17.8	17.62	17.17	17.08	17.42	17.42	17.44	17.17	17.34	17.55	17.04	15.76	15.81	16.17	15.37	15.19	15.1	14.44	15.36	16.98	16.91	16.58	16.28

Table A-6: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, Average (FT1 & W2P) for mean wave period and the Bretschneider spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, Average (FT1 & W2P) for Tm prediction, 2 deg x 2 deg grid, 50 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	32.91	34.73	32.97	34.12	35.4	36.33	37.23	35.84	39.29	40.25	35.63	34.04	35.58	37.57	38.43	35.9	34.81	33.09	35.03	35.68	34.52	32.61	32.83	32.61	33.53	32.5
43	33.29	36.18	35.79	35.94	35.71	37.04	36.87	37.22	38	39.48	36.54	37.43	38.24	36.9	37.33	37.55	36.06	34.54	35.03	36.62	35.61	32.9	32.04	32.34	32.06	33.93
41	34.55	35.08	34.73	36.25	35.75	37.67	39.1	37.09	37.18	36.31	34.94	35.97	38.91	34.58	35.95	35.12	34.94	32.64	34.84	34.52	33.53	32.41	31.82	32.44	32.62	32.17
39	34.87	33.82	35.52	35.78	36.88	35.11	36.53	35.17	36.03	36.46	36.56	34.33	35.84	34.77	34.26	33.36	32.95	33.51	34.67	32.88	32.78	32.99	31.43	32	32.74	30.97
37	34.44	32.94	35.41	33.75	35.36	34.18	34.84	33.91	33.15	34.18	34.23	33.1	32.59	32.85	33.47	33.57	31.15	33.29	33.78	32.02	31.48	31.87	29.67	30.41	30.67	29.97
35	32.08	30.55	32.1	31.56	32.31	30.34	30.85	32.1	31.45	32.1	31.6	31.13	31.53	30.41	31.43	30.74	29.99	29.16	30.91	30.78	30.91	30.4	28.52	29.24	28.99	27.7
33	29.31	30.03	29.28	28.96	28.33	27.56	28.68	28.5	29.88	28.52	28.99	28.69	29.57	28.37	28.32	28.62	29.36	25.53	28.03	27.69	27.54	28.28	27.24	26.23	27.28	26.92
31	25.38	27.42	27.3	25.78	24.5	25.63	26.96	25.55	25.51	25.52	26.92	26.97	25.3	25.77	25.7	26.12	27.07	26.14	24.74	24.77	25.16	25.68	24.75	23.85	25.05	25.43
29	23.62	24.93	23.71	23.93	21.9	23.09	24.71	24.08	22.31	23.11	23.43	24.35	22.22	23.99	24.27	24.22	22.34	24.08	22.52	23	22.13	24.59	22.99	23.08	22.26	23.24
27	22.03	22.19	21.47	22.12	19.97	20.83	21.37	22	20.48	20.7	20.7	20.49	18.27	20.94	22.23	22.54	22.31	21.18	21.65	22.01	20.71	21.86	20.79	20.92	20.91	20.62
25	20.39	20.05	19.48	20.12	19.18	19.27	18.53	19.53	19.86	19.62	19.17	19.32	18.92	17.9	16.75	18.58	20.61	19.75	19.3	19.69	19.14	19.41	19.11	20.9	19.27	18.72
23	19.44	18.42	18.89	18.14	18.19	18.25	17.47	17.54	18.88	18.85	17.81	17.33	18.47	17.63	15.81	16.82	16.59	16.45	17.14	17.08	18.28	18.4	18.65	18.72	18.41	17.24
21	19.15	17.09	17.76	17.28	17.46	17.04	17.22	16.8	17.74	17.94	17.15	16.5	17.9	17.15	15.65	15.8	16.55	15.37	15.17	15.39	13.23	15.3	17.81	16.65	16.78	16.81

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, Average (FT1 & W2P) for Tm prediction, 2 deg x 2 deg grid, 100 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	34.52	36.44	34.58	35.79	37.13	38.09	39.04	37.59	41.22	42.23	37.36	35.68	37.31	39.4	40.33	37.64	36.48	34.66	36.73	37.41	36.19	34.18	34.4	34.17	35.15	34.07
43	34.91	37.96	37.55	37.7	37.46	38.86	38.68	39.04	39.85	41.4	38.32	39.27	40.11	38.68	39.14	39.39	37.82	36.22	36.74	38.4	37.34	34.48	33.58	33.88	33.61	35.58
41	36.24	36.8	36.41	38.02	37.48	39.51	41.03	38.91	38.98	38.07	36.63	37.73	40.81	36.26	37.72	36.83	36.63	34.2	36.55	36.17	35.14	33.96	33.35	34	34.2	33.72
39	36.57	35.47	37.25	37.52	38.67	36.82	38.32	36.87	37.77	38.26	38.35	36.01	37.58	36.46	35.92	34.97	34.54	35.14	36.36	34.47	34.38	34.59	32.96	33.57	34.33	32.48
37	36.11	34.53	37.13	35.38	37.1	35.84	36.54	35.56	34.76	35.84	35.91	34.71	34.18	34.44	35.1	35.19	32.66	34.91	35.42	33.58	33.01	33.41	31.09	31.89	32.17	31.43
35	33.63	32.02	33.65	33.07	33.88	31.8	32.34	33.66	32.97	33.66	33.15	32.64	33.07	31.88	32.96	32.23	31.45	30.56	32.42	32.28	32.42	31.87	29.91	30.67	30.4	29.04
33	30.73	31.49	30.69	30.35	29.68	28.88	30.05	29.87	31.34	29.89	30.39	30.07	31.01	29.74	29.7	30.01	30.78	26.75	29.39	29.03	28.86	29.65	28.56	27.48	28.6	28.23
31	26.59	28.74	28.61	27.01	25.67	26.85	28.26	26.76	26.75	26.73	28.22	28.25	26.5	27.01	26.94	27.38	28.38	27.39	25.92	25.96	26.36	26.91	25.93	24.99	26.25	26.65
29	24.74	26.12	24.83	25.06	22.93	24.18	25.89	25.23	23.35	24.2	24.52	25.5	23.27	25.14	25.44	25.38	23.39	25.21	23.58	24.06	23.16	25.77	24.07	24.18	23.3	24.34
27	23.09	23.23	22.47	23.15	20.88	21.79	22.37	23.03	21.42	21.64	21.66	21.45	19.09	21.92	23.28	23.58	23.35	22.14	22.66	23.02	21.65	22.89	21.75	21.88	21.88	21.56
25	21.35	20.97	20.36	21.04	20.06	20.14	19.36	20.42	20.77	20.51	20.03	20.19	19.78	18.7	17.48	19.42	21.55	20.64	20.17	20.58	20	20.28	19.97	21.85	20.14	19.55
23	20.34	19.27	19.73	18.96	19	19.07	18.24	18.33	19.73	19.69	18.6	18.08	19.29	18.42	16.5	17.56	17.32	17.17	17.88	17.83	19.1	19.21	19.48	19.55	19.23	17.98
21	20.02	17.85	18.56	18.06	18.24	17.79	17.97	17.54	18.52	18.73	17.9	17.22	18.69	17.9	16.32	16.48	17.27	16.03	15.8	16.05	13.78	15.98	18.61	17.36	17.49	17.52

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, Average (FT1 & W2P) for Tm prediction, 4 deg x 4 deg grid, 50 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	33.4	33.75	33.95	34.45	35.49	35.95	36.07	36.61	37.86	37.16	35.99	35.38	36.44	37.15	37.31	36.32	34.84	34.72	34.78	35.03	33.68	33.04	32.29	33.18	32.29	32.18
43	34.34	34.21	34.66	35.24	35.71	36.88	37.11	37.04	38.5	37.65	37.22	36.15	37.39	37.14	36.97	36.24	34.76	34.17	34.34	34.87	34.48	32.79	32.02	32.57	32.64	32.01
41	33.87	35.1	35.43	35.76	36.18	37.04	36.69	37.29	37.11	36.65	35.77	36.72	36.55	36.12	35.47	34.94	34.29	34.08	34.21	34.29	33.4	32.48	31.77	32.27	32.35	31.6
39	34.71	34.62	34.72	35.44	35.53	36.1	35.92	35.55	35.17	35.63	34.54	35.12	34.85	35.21	33.94	34.11	33.36	33.87	34.02	34.04	32.67	32.02	31.05	31.38	31.29	31.22
37	33.73	33.34	33.5	34.23	33.93	34.38	33.73	33.51	33.75	33.43	33.73	33.08	33.07	32.59	33.09	32.37	32.33	31.09	32.81	32.25	31.44	30.76	30.26	30.48	30.99	29.76
35	31.72	31.68	31.26	32.26	31.58	31.04	31.38	31.28	31.27	32.09	31.28	30.49	30.53	30.34	30.72	30.78	29.51	30.09	29.8	30.09	29.74	29.31	28.97	28.78	29.22	28.05
33	29.22	29.3	29.35	28.19	27.85	27.38	28.55	28.86	28.76	28.61	28.93	28.83	28.12	28.3	28.27	28.87	27.85	28.09	27.19	27.67	27.36	27.49	26.9	26.89	26.38	26.33
31	25.87	26.88	26.76	25.22	24.97	25.49	25.78	25.46	25.84	25.57	26.31	27.02	25.62	25.97	26.4	26.73	25.8	25.53	25.6	25.15	24.82	25.09	24.75	24.25	24.64	25.05
29	23.17	23.82	24.49	23.55	22.1	22.89	23.92	23.44	22.76	23.46	23.8	22.79	23.22	23.24	23.82	23.58	23.94	22.98	22.84	23.07	22.95	22.83	22.94	22.53	22.47	22.4
27	21.74	21.78	22.2	21.44	20.56	20.74	22.02	21.19	21.02	20.86	20.72	19.79	19.85	20.51	21.39	21.65	22.38	21.26	21.31	20.87	21.01	20.94	21.2	20.87	20.66	20.42
25	20.65	19.94	20.55	19.45	19.47	18.86	19.12	19.33	19.58	19.19	19.39	18.91	18.26	17.75	18.48	19.26	19.48	19.03	19.58	19.4	19.44	19.63	19.66	19.58	19.2	19.04
23	18.82	18.93	18.42	18.46	18.12	17.8	17.75	18.33	18.09	18.06	17.75	17.76	17.75	17.25	16.73	16.98	17.07	16.94	16.69	17.4	17.75	18.06	18.54	18.33	17.95	17.29
21	17.9	18.12	17.27	17.59	17.41	17.08	17	17.32	17.34	17.34	17.07	17.24	17.42	16.95	15.77	15.83	16.17	15.49	15.32	15.25	14.63	15.53	17.08	17.01	16.72	16.44

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, Average (FT1 & W2P) for Tm prediction, 4 deg x 4 deg grid, 100 year return period

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	35.05	35.41	35.62	36.13	37.22	37.72	37.84	38.39	39.7	38.97	37.73	37.09	38.22	38.95	39.12	38.09	36.53	36.4	36.46	36.73	35.29	34.63	33.84	34.78	33.84	33.73
43	36.03	35.88	36.34	36.96	37.44	38.68	38.91	38.84	40.37	39.47	39.04	37.91	39.2	38.95	38.79	38	36.43	35.81	35.99	36.55	36.16	34.35	33.55	34.13	34.22	33.56
41	35.52	36.82	37.15	37.52	37.93	38.86	38.48	39.11	38.91	38.43	37.5	38.5	38.33	37.88	37.18	36.63	35.97	35.72	35.87	35.94	35.02	34.05	33.3	33.83	33.93	33.13
39	36.41	36.3	36.39	37.16	37.25	37.86	37.67	37.26	36.88	37.36	36.22	36.83	36.57	36.92	35.58	35.77	34.97	35.53	35.68	35.7	34.25	33.57	32.55	32.91	32.82	32.73
37	35.36	34.96	35.1	35.88	35.58	36.04	35.38	35.14	35.4	35.06	35.36	34.71	34.67	34.18	34.69	33.94	33.91	32.59	34.41	33.83	32.99	32.25	31.71	31.96	32.51	31.2
35	33.26	33.22	32.75	33.82	33.11	32.54	32.89	32.8	32.77	33.65	32.81	31.96	32.02	31.81	32.21	32.27	30.93	31.56	31.24	31.55	31.2	30.73	30.37	30.17	30.65	29.41
33	30.62	30.7	30.76	29.54	29.18	28.68	29.92	30.24	30.14	29.98	30.34	30.23	29.47	29.67	29.62	30.26	29.19	29.45	28.51	29.01	28.66	28.81	28.2	28.2	27.65	27.6
31	27.09	28.17	28.03	26.42	26.15	26.71	27.01	26.67	27.07	26.81	27.56	28.33	26.84	27.22	27.67	28.02	27.04	26.74	26.83	26.35	25.98	26.29	25.93	25.4	25.81	26.25
29	24.27	24.94	25.65	24.67	23.13	23.95	25.05	24.55	23.82	24.58	24.93	23.87	24.32	24.34	24.95	24.68	25.07	24.05	23.9	24.17	24.03	23.91	24.02	23.59	23.54	23.45
27	22.76	22.8	23.24	22.44	21.52	21.7	23.06	22.17	22	21.82	21.68	20.68	20.75	21.47	22.4	22.65	23.4	22.25	22.31	21.82	21.97	21.89	22.19	21.84	21.62	21.35
25	21.62	20.88	21.5	20.34	20.36	19.71	19.97	20.2	20.48	20.05	20.28	19.76	19.08	18.54	19.32	20.13	20.35	19.89	20.47	20.27	20.32	20.53	20.54	20.46	20.05	19.89
23	19.67	19.8	19.27	19.29	18.93	18.6	18.54	19.15	18.89	18.86	18.54	18.55	18.54	18.02	17.46	17.74	17.81	17.69	17.42	18.15	18.53	18.85	19.35	19.13	18.75	18.04
21	18.7	18.94	18.05	18.37	18.19	17.83	17.75	18.09	18.09	18.1	17.83	17.99	18.19	17.69	16.44	16.52	16.88	16.14	15.98	15.89	15.24	16.21	17.85	17.73	17.43	17.13

Table A-7: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, Average (FT1 & W2P) for mean wave period and the Ochi spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, Average (FT1 & W2P) for Tm prediction, 2 deg x 2 deg grid, 50 year return period

LONGITUDE

LATITUDE (N)	E										W															
	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	31.83	33.68	31.75	32.71	33.99	34.88	35.74	34.35	37.64	38.61	33.99	32.27	33.71	35.67	36.52	34	32.93	31.31	33.31	33.95	32.79	31.02	31.23	30.98	31.94	30.92
43	32.05	34.98	34.47	34.57	34.34	35.61	35.2	35.54	36.18	37.68	34.75	35.59	36.35	35.01	35.43	35.59	34.13	32.57	33.07	34.63	33.83	31.16	30.31	30.54	30.35	32.2
41	33.33	33.86	33.4	34.88	34.37	36.25	37.42	35.41	35.36	34.52	33.17	34.13	37	32.71	34.07	33.19	33.01	30.69	32.87	32.56	31.77	30.68	30.1	30.65	30.9	30.46
39	33.5	32.45	33.96	34.25	35.35	33.46	34.73	33.38	34.18	34.63	34.73	32.45	33.91	32.85	32.39	31.48	31.07	31.64	32.77	31.01	31.08	31.29	29.75	30.28	30.88	29.14
37	32.94	31.45	33.83	32.02	33.62	32.45	33.07	32.15	31.32	32.37	32.42	31.2	30.68	30.94	31.62	31.72	29.34	31.43	32	30.27	29.76	30.07	27.91	28.71	28.95	28.26
35	30.59	29.06	30.53	29.85	30.6	28.65	29.12	30.36	29.65	30.31	29.82	29.27	29.64	28.54	29.61	28.94	28.2	27.37	29.17	29.05	29.19	28.63	26.78	27.56	27.29	26.03
33	27.88	28.6	27.65	27.28	26.66	25.86	26.96	26.78	28.1	26.79	27.25	26.87	27.78	26.6	26.64	26.93	27.65	23.88	26.35	26.02	25.88	26.59	25.57	24.54	25.58	25.23
31	23.9	25.9	25.7	24.2	22.95	24.06	25.25	23.87	23.87	23.83	25.19	25.32	23.72	24.18	24.12	24.52	25.45	24.4	23.13	23.17	23.55	24.01	23.1	22.29	23.42	23.79
29	22.17	23.46	22.18	22.39	20.42	21.57	23.06	22.45	20.75	21.49	21.8	22.76	20.71	22.44	22.71	22.66	20.83	22.4	20.97	21.44	20.6	22.94	21.4	21.54	20.71	21.66
27	20.68	20.84	20.09	20.67	18.57	19.4	19.87	20.47	19.03	19.27	19.27	19.06	16.86	19.44	20.68	20.95	20.72	19.67	20.1	20.45	19.16	20.25	19.22	19.35	19.39	19.11
25	19.17	18.83	18.21	18.75	17.84	17.88	17.12	18.08	18.4	18.25	17.82	17.91	17.52	16.54	15.43	17.19	19.15	18.27	17.79	18.16	17.59	17.84	17.55	19.27	17.73	17.2
23	18.23	17.24	17.63	16.83	16.88	16.89	16.1	16.17	17.45	17.5	16.5	15.99	17.09	16.28	14.53	15.5	15.28	15.11	15.72	15.67	16.77	16.87	17.1	17.19	16.91	15.78
21	18.04	16.01	16.62	16.07	16.24	15.74	15.91	15.51	16.4	16.63	15.87	15.24	16.6	15.87	14.4	14.52	15.24	14.07	13.86	14.06	12.01	13.92	16.3	15.23	15.33	15.36

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, Average (FT1 & W2P) for Tm prediction, 2 deg x 2 deg grid, 100 year return period

LONGITUDE

LATITUDE (N)	E										W															
	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	33.36	35.31	33.26	34.27	35.62	36.53	37.45	35.99	39.44	40.46	35.59	33.8	35.3	37.36	38.28	35.61	34.47	32.76	34.88	35.56	34.33	32.48	32.69	32.44	33.45	32.38
43	33.58	36.66	36.13	36.22	35.99	37.32	36.88	37.24	37.89	39.47	36.41	37.29	38.07	36.66	37.1	37.3	35.75	34.1	34.63	36.26	35.43	32.62	31.74	31.96	31.78	33.72
41	34.92	35.49	34.99	36.55	36	37.97	39.22	37.11	37.02	36.16	34.72	35.77	38.76	34.26	35.69	34.76	34.57	32.13	34.44	34.07	33.26	32.11	31.51	32.08	32.36	31.88
39	35.1	33.99	35.57	35.88	37.03	35.05	36.39	34.95	35.79	36.29	36.38	33.99	35.52	34.41	33.92	32.95	32.53	33.13	34.33	32.47	32.57	32.77	31.16	31.73	32.34	30.51
37	34.51	32.93	35.43	33.52	35.23	33.98	34.64	33.67	32.8	33.9	33.97	32.68	32.13	32.4	33.11	33.22	30.73	32.92	33.53	31.71	31.17	31.49	29.21	30.07	30.33	29.61
35	32.03	30.43	31.97	31.24	32.04	29.99	30.49	31.8	31.04	31.75	31.24	30.65	31.05	29.88	31.01	30.31	29.54	28.65	30.57	30.43	30.59	29.98	28.06	28.87	28.59	27.26
33	29.19	29.95	28.94	28.55	27.9	27.06	28.21	28.03	29.43	28.04	28.53	28.13	29.09	27.85	27.9	28.2	28.96	25	27.59	27.24	27.09	27.85	26.78	25.69	26.8	26.43
31	25	27.12	26.89	25.33	24.02	25.17	26.44	24.98	24.99	24.94	26.38	26.5	24.82	25.31	25.25	25.67	26.65	25.53	24.21	24.25	24.65	25.13	24.18	23.32	24.52	24.9
29	23.19	24.55	23.2	23.42	21.35	22.57	24.13	23.48	21.69	22.48	22.79	23.81	21.67	23.49	23.78	23.72	21.78	23.42	21.94	22.41	21.54	24.02	22.37	22.54	21.66	22.66
27	21.65	21.79	21	21.6	19.39	20.27	20.76	21.4	19.88	20.13	20.14	19.93	17.6	20.32	21.62	21.89	21.67	20.53	21.01	21.36	20.01	21.17	20.07	20.21	20.27	19.96
25	20.04	19.67	19.01	19.59	18.63	18.66	17.87	18.88	19.21	19.06	18.59	18.7	18.29	17.26	16.08	17.95	20	19.07	18.56	18.96	18.36	18.6	18.31	20.12	18.5	17.93
23	19.05	18.01	18.4	17.57	17.61	17.63	16.79	16.87	18.21	18.26	17.21	16.67	17.83	16.98	15.14	16.16	15.94	15.75	16.38	16.33	17.49	17.59	17.84	17.92	17.63	16.44
21	18.84	16.72	17.35	16.77	16.95	16.42	16.58	16.17	17.11	17.34	16.54	15.89	17.31	16.55	14.99	15.13	15.88	14.65	14.41	14.65	12.48	14.51	17	15.85	15.95	15.99

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, Average (FT1 & W2P) for Tm prediction, 4 deg x 4 deg grid, 50 year return period

LONGITUDE

LATITUDE (N)	E										W															
	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	32.33	32.68	32.74	33.03	34.09	34.5	34.59	35.13	36.2	35.51	34.35	33.61	34.56	35.26	35.41	34.43	32.96	32.92	33.06	33.31	31.95	31.45	30.7	31.55	30.7	30.6
43	33.11	32.98	33.33	33.86	34.34	35.45	35.43	35.36	36.67	35.86	35.43	34.31	35.49	35.25	35.08	34.3	32.84	32.2	32.38	32.91	32.71	31.05	30.29	30.77	30.92	30.3
41	32.63	33.88	34.11	34.39	34.81	35.61	35.02	35.61	35.28	34.86	33.99	34.88	34.66	34.24	33.59	33.01	32.38	32.11	32.26	32.33	31.64	30.75	30.04	30.47	30.63	29.89
39	33.34	33.25	33.15	33.9	33.99	34.45	34.13	33.76	33.32	33.81	32.73	33.22	32.94	33.29	32.08	32.22	31.48	31.99	32.13	32.15	30.98	30.33	29.37	29.66	29.45	29.38
37	32.24	31.85	31.93	32.5	32.2	32.64	31.97	31.76	31.92	31.62	31.92	31.19	31.15	30.68	31.25	30.54	30.51	29.26	31.05	30.5	29.72	28.98	28.49	28.78	29.27	28.05
35	30.23	30.19	29.69	30.55	29.87	29.34	29.65	29.54	29.47	30.3	29.5	28.64	28.66	28.47	28.91	28.97	27.73	28.28	28.08	28.36	28.04	27.56	27.22	27.1	27.52	26.38
33	27.79	27.86	27.72	26.52	26.19	25.68	26.84	27.13	26.99	26.88	27.19	27.01	26.36	26.53	26.59	27.17	26.17	26.39	25.52	26	25.7	25.81	25.23	25.19	24.71	24.66
31	24.38	25.37	25.17	23.66	23.41	23.92	24.1	23.79	24.18	23.89	24.6	25.37	24.04	24.37	24.8	25.12	24.21	23.8	23.97	23.53	23.22	23.43	23.1	22.67	23.02	23.42
29	21.73	22.36	22.94	22.03	20.61	21.38	22.29	21.82	21.18	21.83	22.16	21.25	21.69	21.71	22.28	22.03	22.38	21.33	21.28	21.51	21.4	21.24	21.34	21	20.92	20.85
27	20.4	20.44	20.81	20	19.15	19.31	20.49	19.69	19.55	19.43	19.29	18.38	18.38	19.02	19.86	20.08	20.79	19.74	19.77	19.34	19.46	19.35	19.61	19.3	19.15	18.92
25	19.41	18.72	19.25	18.1	18.12	17.48	17.69	17.89	18.12	17.83	18.02	17.51	16.88	16.4	17.1	17.85	18.06	17.58	18.06	17.89	17.88	18.04	18.07	18.01	17.66	17.5
23	17.63	17.73	17.17	17.14	16.81	16.46	16.38	16.93	16.69	16.74	16.44	16.41	16.4	15.92	15.41	15.66	15.74	15.58	15.29	15.97	16.26	16.54	17	16.81	16.46	15.84
21	16.81	17.03	16.14	16.37	16.19	15.78	15.7	16.01	16.02	16.06	15.8	15.95	16.13	15.68	14.52	14.56	14.88	14.19	14	13.93	13.32	14.13	15.6	15.57	15.28	15.01

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi storm spectrum, Average (FT1 & W2P) for Tm prediction, 4 deg x 4 deg grid, 100 year return period

LONGITUDE

LATITUDE (N)	E										W															
	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	33.89	34.26	34.32	34.61	35.71	36.15	36.24	36.8	37.92	37.2	35.96	35.19	36.2	36.92	37.08	36.05	34.52	34.47	34.62	34.88	33.44	32.92	32.14	33.04	32.14	32.04
43	34.71	34.56	34.91	35.48	35.97	37.14	37.11	37.04	38.4	37.55	37.12	35.94	37.17	36.92	36.75	35.92	34.37	33.7	33.9	34.44	34.27	32.49	31.7	32.21	32.38	31.72
41	34.2	35.51	35.73	36.04	36.46	37.32	36.68	37.31	36.95	36.51	35.59	36.53	36.3	35.86	35.16	34.57	33.92	33.61	33.77	33.84	33.13	32.19	31.45	31.91	32.09	31.3
39	34.93	34.83	34.71	35.52	35.61	36.08	35.75	35.34	34.9	35.41	34.28	34.8	34.52	34.87	33.59	33.74	32.95	33.52	33.66	33.68	32.44	31.76	30.76	31.07	30.85	30.76
37	33.75	33.36	33.41	34.02	33.72	34.18	33.49	33.26	33.44	33.12	33.42	32.68	32.62	32.13	32.71	31.99	31.95	30.64	32.52	31.96	31.15	30.35	29.83	30.14	30.67	29.38
35	31.66	31.62	31.08	31.98	31.28	30.71	31.04	30.95	30.85	31.73	30.91	29.98	30.02	29.81	30.27	30.34	29.03	29.63	29.41	29.7	29.39	28.86	28.51	28.38	28.84	27.63
33	29.09	29.16	29.01	27.76	27.41	26.87	28.09	28.4	28.26	28.13	28.48	28.29	27.59	27.79	27.83	28.45	27.4	27.63	26.74	27.23	26.9	27.02	26.43	26.38	25.87	25.82
31	25.5	26.56	26.33	24.75	24.49	25.03	25.22	24.89	25.3	25.01	25.74	26.57	25.15	25.52	25.97	26.3	25.34	24.91	25.1	24.63	24.28	24.52	24.18	23.72	24.09	24.52
29	22.74	23.39	24	23.04	21.54	22.34	23.31	22.83	22.14	22.84	23.19	22.23	22.69	22.71	23.31	23.04	23.42	22.3	22.25	22.51	22.39	22.22	22.32	21.96	21.88	21.8
27	21.33	21.37	21.76	20.91	20.02	20.18	21.44	20.57	20.44	20.3	20.16	19.19	19.2	19.89	20.78	20.99	21.72	20.64	20.67	20.2	20.32	20.21	20.5	20.18	20.01	19.75
25	20.31	19.58	20.11	18.91	18.93	18.25	18.45	18.67	18.93	18.61	18.83	18.29	17.62	17.1	17.85	18.64	18.85	18.35	18.85	18.67	18.66	18.84	18.86	18.79	18.41	18.26
23	18.4	18.52	17.94	17.89	17.54	17.18	17.08	17.66	17.41	17.47	17.16	17.11	17.1	16.61	16.07	16.33	16.4	16.25	15.94	16.64	16.95	17.25	17.72	17.52	17.17	16.49
21	17.55	17.78	16.86	17.07	16.89	16.45	16.38	16.7	16.7	16.73	16.48	16.63	16.83	16.34	15.11	15.16	15.51	14.76	14.58	14.5	13.86	14.73	16.27	16.21	15.9	15.62

Table A-8: Most probable extreme wave amplitudes (RMS) predicted using the Alves and Young's extreme Hs data and a wave simulation (3 hrs) using the Pierson-Moskowitz spectrum

Extreme wave amplitude (in meters) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 50 year return period (Northern Pacific Region), 3 hr storm duration

	LONGITUDE																									
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	15.97	17.89	17.02	17.17	18.27	19.23	19.07	17.70	20.58	20.85	18.48	17.04	18.84	20.68	19.80	18.01	17.35	17.02	18.62	18.22	17.82	16.15	16.71	15.79	16.97	16.28
43	16.44	18.43	16.34	18.13	17.87	18.38	19.40	20.18	19.04	21.34	18.49	18.24	19.27	19.15	20.40	18.82	18.23	17.17	16.99	18.38	17.89	16.41	16.58	16.59	17.01	17.15
41	18.00	18.21	17.72	19.13	16.76	19.07	19.87	18.95	18.98	18.35	19.38	17.85	19.88	17.62	18.10	17.13	17.52	16.24	17.33	18.44	16.99	15.92	16.43	16.82	17.01	16.16
39	17.57	17.88	18.76	17.66	18.34	17.30	18.54	18.89	18.86	17.14	18.95	17.75	17.34	17.82	17.44	17.69	16.46	17.13	17.44	18.08	16.98	16.38	15.80	16.09	17.10	16.13
37	17.15	16.40	18.16	17.05	18.03	16.44	17.60	16.25	17.03	17.76	16.65	16.68	16.91	16.15	17.09	16.95	15.53	16.06	17.05	15.81	15.74	15.78	15.27	14.77	15.52	14.94
35	16.87	15.87	15.77	15.05	17.51	15.32	15.19	16.41	15.96	16.56	16.33	15.65	17.27	15.08	16.04	15.57	14.89	14.95	15.73	15.25	15.48	15.82	14.68	15.17	15.46	13.82
33	15.44	15.79	14.08	13.90	14.02	14.70	15.15	15.25	15.17	15.09	14.48	15.45	14.94	15.29	15.19	14.55	14.76	12.72	13.33	14.23	13.49	15.21	13.32	13.32	14.98	13.48
31	13.09	13.38	13.88	13.78	12.33	12.79	14.00	13.90	12.78	13.31	13.62	13.62	12.92	12.44	13.07	14.52	13.79	13.08	13.14	12.09	12.74	12.78	12.85	12.36	12.66	12.84
29	11.50	12.59	11.86	12.09	11.38	12.06	13.00	11.67	11.01	11.90	12.53	12.69	11.47	11.93	11.94	12.04	11.24	12.32	11.58	11.77	11.35	13.19	11.34	11.54	11.44	11.39
27	11.09	11.42	11.08	11.71	10.03	10.64	10.89	11.77	10.09	10.14	10.88	9.92	8.79	10.50	10.93	11.88	11.59	10.39	10.57	10.90	10.48	11.56	11.12	10.87	10.17	10.75
25	10.85	10.32	10.33	10.56	9.82	9.28	9.51	10.36	10.54	10.25	9.59	10.29	9.73	9.23	8.56	9.55	10.23	9.76	9.56	9.94	9.79	10.02	9.94	10.71	9.27	9.66
23	10.09	8.82	10.07	9.27	9.66	9.04	8.89	8.60	9.31	9.85	9.11	9.13	8.97	8.68	8.41	8.78	8.26	8.44	8.65	8.89	9.11	8.99	9.41	9.37	9.12	8.59
21	9.36	8.90	9.02	8.90	8.81	8.57	9.05	8.82	8.98	9.04	8.68	8.66	8.67	9.38	7.46	7.70	8.41	7.76	7.97	7.60	7.07	7.86	8.98	8.42	8.48	9.10

Extreme wave amplitude (in meters) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 100 year return period (Northern Pacific Region), 3 hr storm duration

	LONGITUDE																									
	E										W															
LATITUDE (N) 0	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	17.61	17.77	17.39	18.84	19.42	19.10	19.98	18.39	21.18	21.28	18.53	17.83	19.04	20.12	21.44	19.42	18.16	17.93	18.84	19.42	18.47	17.02	16.85	17.03	17.44	17.44
43	18.38	19.23	19.32	18.77	18.20	19.81	19.31	19.82	20.83	22.10	18.80	19.18	18.94	20.75	20.28	20.15	19.74	17.83	18.39	18.58	19.25	18.36	17.26	18.14	17.26	17.32
41	19.09	18.90	17.91	19.26	19.24	19.45	21.56	19.32	20.03	19.62	18.18	18.32	21.49	18.58	20.13	19.65	18.59	17.43	18.58	18.13	17.73	16.95	17.67	17.87	17.20	16.66
39	18.43	18.20	18.57	19.15	20.64	19.32	20.50	18.57	18.60	18.85	19.60	19.62	19.34	19.12	18.05	18.42	18.18	17.38	17.92	17.24	17.25	17.93	16.60	17.29	16.39	16.14
37	19.83	17.80	19.34	18.29	19.20	18.94	19.60	18.00	18.09	17.43	18.45	18.39	16.69	16.82	18.21	16.98	18.01	17.36	17.47	18.18	16.46	16.67	16.10	15.58	16.00	16.04
35	17.94	16.58	18.12	16.59	17.09	16.13	15.99	17.26	18.05	17.63	16.43	16.55	16.85	16.86	16.25	16.51	17.03	15.57	16.27	17.30	15.89	16.01	15.05	15.18	15.71	14.76
33	15.34	15.39	15.50	15.27	15.42	15.75	15.85	14.39	16.44	15.80	15.74	15.47	16.01	14.87	15.15	15.15	14.98	15.45	14.67	14.74	13.83	14.46	14.45	14.45	14.77	13.81
31	14.75	15.12	14.05	13.75	13.38	13.81	14.44	14.16	13.28	13.23	14.18	14.21	14.41	14.44	14.07	14.01	14.17	13.99	12.71	13.44	12.94	14.34	13.48	13.61	13.83	14.18
29	12.64	12.80	13.38	13.12	10.95	12.54	13.59	12.41	11.68	11.81	13.25	14.12	11.74	13.07	13.01	13.07	11.50	12.49	12.21	12.46	11.89	12.81	12.02	12.53	11.98	12.24
27	10.97	11.44	11.74	11.32	10.39	11.06	11.03	12.65	10.94	11.05	10.74	10.52	10.13	10.78	12.43	11.48	11.74	11.56	11.88	11.44	10.49	11.65	11.29	11.16	10.98	10.74
25	11.25	10.83	10.66	9.94	10.08	11.04	10.14	10.20	10.26	10.10	10.40	10.37	10.47	9.77	9.20	9.79	11.13	10.38	10.56	10.19	10.91	9.92	10.28	10.96	10.56	10.19
23	10.57	10.23	9.56	9.61	9.32	10.32	9.16	9.70	9.67	10.25	9.22	9.26	10.12	9.98	8.17	9.33	9.04	8.29	8.61	9.04	10.04	9.50	9.67	10.42	9.73	9.07
21	10.12	8.63	8.87	9.24	9.89	8.86	9.45	9.49	9.32	9.40	9.29	8.68	9.86	9.04	8.32	8.18	9.07	7.94	7.90	8.51	6.71	8.01	9.44	8.59	8.78	8.85

Table A-9: Most probable extreme wave amplitudes (RMS) predicted using the Alves and Young's extreme Hs data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Extreme wave amplitude (in meters) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 50 year return period (Northern Pacific Region), 3 day storm duration

		LONGITUDE																									
		E										W															
		161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	20.16	20.70	19.73	20.80	21.85	22.04	22.38	21.80	23.48	24.30	21.99	20.82	21.68	23.10	23.73	22.21	21.03	20.60	21.01	21.65	21.32	20.17	19.95	19.95	19.93	19.46
	43	20.48	21.52	21.54	22.32	21.80	22.93	22.22	22.43	23.08	24.34	22.30	22.62	23.57	22.49	22.83	22.96	22.07	21.66	21.60	22.77	21.74	20.04	18.90	19.79	19.54	20.72
	41	20.97	21.48	20.91	21.82	21.82	22.50	23.66	22.70	22.84	22.20	21.25	22.01	24.17	21.02	22.45	21.76	21.79	19.82	21.49	21.05	20.72	19.73	19.38	19.89	19.73	19.60
	39	20.67	20.49	21.56	22.32	22.34	21.42	22.37	21.44	21.97	22.25	22.22	21.22	22.10	21.14	20.89	20.28	20.36	20.54	21.19	19.79	19.69	20.00	19.54	19.41	20.22	19.00
	37	21.14	20.10	21.41	20.76	22.08	20.88	21.01	20.83	20.24	21.02	21.07	19.96	19.99	20.22	20.30	20.83	19.14	20.52	20.82	19.62	19.07	19.51	18.27	18.81	18.98	18.47
	35	19.28	18.75	19.76	19.48	20.11	18.68	18.92	19.61	19.82	20.17	19.14	19.06	19.61	19.06	19.22	18.98	18.33	17.92	18.94	18.67	19.28	18.62	17.55	18.26	18.13	16.94
	33	17.87	18.46	17.92	17.86	17.18	16.89	17.41	17.15	18.36	17.26	17.99	17.24	18.17	17.42	17.19	17.13	17.77	15.27	17.04	16.63	16.96	17.63	16.72	16.13	16.55	16.94
	31	15.26	16.50	16.30	15.95	15.03	15.83	16.29	15.76	15.52	15.51	16.49	16.86	15.49	16.00	15.89	16.09	16.33	15.85	14.96	14.74	15.56	15.61	15.35	14.68	15.42	15.42
	29	14.69	15.24	14.24	14.54	13.44	13.93	15.07	14.91	13.51	13.81	14.41	14.90	13.66	14.47	14.67	14.87	13.78	15.03	13.61	13.93	13.67	14.97	14.00	14.21	13.58	13.89
	27	13.43	13.61	12.82	13.56	11.96	12.79	13.14	13.36	12.19	12.52	12.42	12.54	10.90	12.94	13.62	13.92	13.42	12.83	13.38	13.53	12.51	13.43	12.83	12.78	12.74	12.78
	25	12.29	12.15	11.95	12.18	11.74	11.69	11.42	12.09	12.11	12.08	11.74	11.90	11.52	10.89	10.34	11.35	12.62	12.00	11.71	12.00	11.68	11.66	11.70	12.79	11.85	11.13
	23	11.84	11.43	11.25	10.94	10.99	11.02	10.76	10.53	11.67	11.46	10.58	10.60	11.19	10.86	9.55	10.10	10.01	10.08	10.52	10.36	11.08	11.20	11.48	11.51	11.36	10.39
	21	11.75	10.25	10.57	10.46	10.53	10.23	10.73	10.19	10.69	11.06	10.24	9.89	10.64	10.31	9.47	9.50	10.03	9.47	9.24	9.37	8.06	9.38	10.70	10.35	10.10	10.51

Extreme wave amplitude (in meters) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 100 year return period (Northern Pacific Region), 3 day storm duration

		LONGITUDE																									
		E										W															
	0	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	20.71	22.16	20.75	21.55	23.05	23.17	23.65	22.77	24.93	25.84	23.07	22.27	23.01	23.97	24.83	23.55	22.53	20.90	22.22	22.15	21.86	20.86	21.17	21.14	21.82	21.01
	43	21.12	23.30	23.09	22.94	22.61	23.53	23.22	24.00	24.53	25.66	23.71	24.00	24.25	23.37	24.28	24.36	23.18	22.28	22.27	23.55	22.78	21.54	20.46	21.00	20.63	21.90
	41	21.99	22.67	21.69	23.33	22.44	24.24	25.18	23.44	23.75	23.48	22.37	23.53	24.79	22.23	23.45	22.53	22.38	21.10	22.53	22.52	21.34	20.71	20.26	20.77	21.02	20.31
	39	21.93	21.57	23.07	22.97	23.60	22.57	23.65	22.30	22.81	23.19	23.14	22.02	23.20	22.35	21.71	20.95	21.54	21.39	22.48	21.01	20.86	21.35	20.21	20.57	21.03	19.40
	37	22.08	20.99	23.07	22.02	22.79	22.35	22.16	21.84	20.96	22.24	22.00	21.29	20.94	21.04	21.57	21.37	20.03	21.81	21.71	20.36	20.53	20.24	19.25	19.54	19.91	19.07
	35	20.73	19.35	20.52	20.41	20.61	19.70	19.78	20.76	20.09	20.67	20.16	19.73	20.04	19.90	20.25	19.81	19.17	18.91	19.73	19.99	19.61	19.45	18.59	18.83	18.17	17.73
	33	18.95	18.81	18.48	18.68	17.94	17.85	18.35	18.43	19.28	18.50	18.53	18.48	19.05	17.92	18.25	18.24	18.81	16.41	18.00	17.50	17.69	18.10	17.23	16.96	17.41	17.29
	31	15.95	17.46	17.58	16.38	15.94	16.41	17.30	16.38	16.48	16.28	17.23	17.36	16.34	16.72	16.75	17.02	17.35	16.63	16.01	16.05	16.10	16.63	15.83	15.16	16.18	16.36
	29	15.31	15.85	15.06	15.21	13.80	14.82	16.03	15.72	14.17	14.82	14.89	15.69	13.97	15.54	15.42	15.44	14.26	15.73	14.28	14.83	13.99	15.73	14.58	14.80	14.13	14.63
	27	14.20	14.01	13.88	14.18	12.72	13.23	13.89	14.17	13.02	13.25	13.31	13.15	11.55	13.56	14.27	14.25	14.07	13.30	13.83	14.29	13.28	14.16	13.27	13.41	13.45	13.19
	25	12.85	12.41	12.21	12.83	12.22	12.53	11.82	12.45	12.59	12.58	12.23	12.34	12.29	11.41	10.48	11.89	13.11	12.91	12.28	12.51	12.21	12.52	12.37	13.30	12.34	12.05
	23	12.20	11.89	12.12	11.62	11.28	11.59	10.96	11.19	12.05	12.08	11.61	10.87	11.78	11.26	10.18	10.81	10.53	10.74	10.80	10.81	11.69	11.93	12.05	12.04	11.90	11.32
	21	12.01	10.86	11.18	10.90	11.07	10.72	10.99	10.85	11.30	11.64	11.07	10.74	11.68	10.94	10.05	10.13	10.55	9.99	9.61	10.02	8.34	9.62	11.42	10.46	10.75	10.73

Table A-10: Most probable extreme wave heights predicted using the Alves and Young's extreme Hs data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Extreme wave height (in meters) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 50 year return period (Northern Pacific Region), 3 day storm duration

		LONGITUDE E										LONGITUDE W															
		161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	34.81	36.26	34.48	36.56	38.24	38.52	38.82	38.27	40.65	42.10	38.09	36.37	37.94	40.14	40.76	38.75	36.66	35.14	36.70	37.79	37.09	35.19	35.07	34.55	35.00	34.32
	43	35.44	38.09	37.72	38.84	37.66	39.89	39.01	39.16	40.06	42.58	39.08	39.47	40.91	39.15	40.14	40.38	38.82	36.95	37.39	39.81	37.79	35.24	33.71	35.05	34.62	36.47
	41	36.85	37.86	36.80	38.27	37.48	39.46	41.32	39.58	39.86	38.89	37.41	38.42	41.76	36.56	39.09	38.16	37.47	34.75	36.90	36.73	36.05	34.19	34.08	34.77	34.18	34.55
	39	36.44	35.62	37.54	38.81	39.24	37.67	38.97	36.91	38.26	38.50	38.90	37.40	38.78	37.48	36.72	34.91	35.22	36.07	37.15	34.52	34.26	35.15	34.32	33.84	35.02	32.53
	37	36.79	35.02	37.15	36.22	38.30	36.35	36.87	36.20	35.43	36.95	36.29	35.08	34.53	34.45	35.37	35.95	33.68	35.54	36.55	34.54	33.51	33.73	31.85	32.93	32.90	31.57
	35	33.87	32.62	34.38	33.88	34.81	32.52	33.01	34.08	34.09	34.97	33.67	33.28	34.25	32.84	33.76	33.10	32.32	31.53	32.61	32.62	33.44	32.73	30.75	31.63	31.36	29.54
	33	31.37	31.77	31.04	31.25	29.79	28.98	30.27	29.74	31.63	30.37	30.90	30.33	31.69	30.41	29.73	29.79	30.83	26.72	29.54	29.26	29.30	30.62	29.03	28.16	28.81	29.27
	31	26.59	28.67	28.51	27.38	26.18	27.44	28.34	27.21	27.03	27.22	28.96	29.17	26.78	27.80	27.67	28.13	28.29	27.44	26.19	26.40	26.77	27.25	26.36	25.23	26.54	27.07
	29	25.24	26.69	24.54	25.11	23.01	24.06	26.21	25.88	23.59	24.39	24.89	26.04	23.88	25.53	25.29	26.07	23.54	26.07	23.82	24.64	23.50	26.30	24.05	25.01	23.78	24.28
	27	23.01	24.01	22.66	23.43	20.91	21.76	22.68	23.33	21.26	21.89	21.62	21.60	19.12	22.48	23.83	24.23	23.49	22.15	23.15	23.32	22.20	23.02	22.27	22.42	22.00	21.95
	25	21.35	20.98	20.51	21.46	20.28	20.23	19.73	20.74	20.69	20.88	20.10	20.84	19.85	18.72	17.89	19.79	21.48	20.90	20.34	20.91	20.28	20.24	20.06	22.23	20.49	19.40
	23	20.31	19.39	19.42	19.03	19.26	19.15	18.69	18.21	20.06	19.68	18.35	18.51	19.34	18.76	16.47	17.46	17.52	17.30	18.39	17.93	19.38	19.57	19.81	19.79	19.54	18.22
	21	20.40	17.70	18.32	18.05	18.12	17.81	18.53	17.58	18.66	18.85	17.76	16.94	18.46	17.87	16.40	16.42	17.53	16.23	15.89	16.33	13.90	16.06	18.86	17.76	17.50	18.18

Extreme wave height (in meters) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 100 year return period (Northern Pacific Region), 3 day storm duration

		LONGITUDE E										LONGITUDE W															
	0	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	36.41	38.66	35.91	38.01	40.14	40.34	41.13	39.61	44.05	45.15	40.48	38.77	40.25	41.62	43.60	40.88	39.13	36.10	38.87	39.27	37.96	36.62	36.52	36.49	38.11	36.28
	43	37.18	40.70	40.46	40.25	39.66	41.07	40.51	41.72	42.57	44.32	41.00	41.82	42.75	41.28	42.34	42.49	40.30	38.77	39.44	41.23	40.24	37.87	35.51	36.31	36.25	38.26
	41	38.58	39.52	38.86	40.34	39.77	42.34	43.55	40.76	41.68	40.53	39.09	40.80	43.26	39.10	40.74	39.60	38.76	37.22	39.45	39.17	37.02	36.32	35.57	35.93	36.43	35.36
	39	38.37	37.54	40.73	39.77	40.70	38.67	40.95	38.81	39.97	40.25	40.16	38.39	40.92	39.17	37.86	36.70	37.00	37.84	39.16	36.31	36.85	37.26	35.33	36.04	36.54	34.08
	37	38.16	37.23	40.26	38.06	39.89	38.44	38.61	37.61	36.63	38.97	38.22	37.30	36.61	36.60	37.66	37.50	34.68	37.67	38.18	35.87	35.59	35.38	33.17	33.70	34.54	33.81
	35	36.51	34.33	35.71	35.87	35.81	34.47	34.42	36.08	34.90	36.10	35.87	34.91	35.26	34.41	35.66	34.51	33.42	32.43	34.05	35.05	34.17	33.99	32.34	32.42	32.00	31.01
	33	32.59	32.31	32.94	32.24	31.25	30.81	31.78	32.12	33.70	32.03	32.46	32.58	32.98	31.87	31.69	31.73	32.78	28.47	31.29	30.63	31.02	31.17	30.55	29.44	30.18	29.73
	31	27.91	30.80	30.62	28.85	27.49	28.08	30.06	28.31	28.62	28.42	29.86	30.05	28.16	29.30	28.96	29.49	29.90	29.12	28.49	27.85	27.70	28.59	27.59	26.65	27.82	28.51
	29	26.61	27.64	26.40	26.84	24.50	26.11	28.01	27.16	24.96	25.81	25.89	26.93	24.21	26.68	26.82	26.95	24.82	27.04	25.01	25.51	24.07	27.44	25.66	25.65	24.94	25.90
	27	24.65	24.32	23.80	24.66	22.55	22.82	24.24	24.88	22.62	23.03	23.18	22.75	20.24	23.79	24.80	24.82	24.77	23.22	23.74	24.78	23.28	24.54	23.27	23.15	23.34	22.91
	25	22.52	21.87	21.19	22.45	21.29	21.68	20.38	21.71	21.85	21.52	21.09	21.34	21.22	19.59	18.06	20.78	22.65	21.91	21.10	21.72	20.83	21.60	21.21	23.13	21.38	20.56
	23	21.49	20.51	20.73	19.96	19.55	20.29	19.12	19.43	21.23	21.24	20.09	19.02	20.66	19.25	17.61	18.45	18.12	18.29	19.11	18.53	20.08	20.65	20.81	20.71	20.36	19.38
	21	20.69	18.71	19.60	19.17	19.13	18.65	18.89	18.32	19.66	20.31	18.93	18.36	20.08	19.23	17.28	17.31	18.15	17.12	16.55	17.31	14.49	16.68	19.73	18.16	18.75	18.58

Table A-11: Extreme wave zero crossing period predicted using the Alves and Young's extreme Hs data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Extreme Mean Zero Crossing Period (in seconds) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 50 year return period (Northern Pacific Region), 3 day storm duration

		LONGITUDE																									
		E										W															
		161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	16.24	16.64	16.26	16.55	16.82	17.03	17.22	16.93	17.67	17.86	16.90	16.58	16.92	17.35	17.54	17.00	16.75	16.37	16.79	16.94	16.69	16.23	16.28	16.24	16.43	16.21
	43	16.34	16.96	16.90	16.93	16.88	17.18	17.17	17.25	17.45	17.72	17.12	17.31	17.49	17.20	17.30	17.36	17.03	16.73	16.80	17.16	16.91	16.33	16.12	16.21	16.13	16.56
	41	16.61	16.74	16.66	17.00	16.90	17.29	17.63	17.23	17.26	17.07	16.78	17.00	17.64	16.71	17.00	16.83	16.80	16.30	16.77	16.71	16.46	16.22	16.08	16.22	16.26	16.15
	39	16.70	16.48	16.89	16.91	17.18	16.79	17.11	16.83	17.02	17.09	17.12	16.66	16.99	16.76	16.64	16.45	16.35	16.47	16.74	16.34	16.28	16.34	15.99	16.12	16.32	15.91
	37	16.62	16.29	16.84	16.52	16.86	16.59	16.75	16.54	16.40	16.61	16.62	16.39	16.27	16.34	16.46	16.49	15.94	16.44	16.50	16.12	15.99	16.09	15.60	15.75	15.82	15.65
	35	16.10	15.74	16.13	16.01	16.18	15.73	15.85	16.13	16.01	16.15	16.03	15.94	16.04	15.78	16.00	15.84	15.67	15.48	15.88	15.85	15.88	15.75	15.31	15.48	15.43	15.11
	33	15.46	15.62	15.49	15.42	15.26	15.09	15.35	15.30	15.65	15.33	15.44	15.37	15.57	15.29	15.26	15.33	15.51	14.58	15.19	15.11	15.07	15.26	15.00	14.75	15.01	14.93
	31	14.53	15.02	15.01	14.63	14.31	14.58	14.94	14.59	14.58	14.59	14.93	14.92	14.50	14.63	14.61	14.72	14.95	14.75	14.39	14.37	14.48	14.62	14.40	14.13	14.45	14.55
	29	14.06	14.40	14.10	14.16	13.61	13.93	14.38	14.21	13.74	13.95	14.04	14.26	13.70	14.17	14.24	14.23	13.74	14.22	13.78	13.93	13.69	14.34	13.93	13.94	13.73	13.99
	27	13.63	13.67	13.49	13.67	13.08	13.32	13.48	13.65	13.22	13.28	13.28	13.23	12.60	13.36	13.71	13.82	13.75	13.43	13.56	13.66	13.30	13.63	13.33	13.37	13.36	13.28
	25	13.17	13.06	12.92	13.12	12.84	12.87	12.67	12.96	13.06	12.97	12.86	12.90	12.78	12.49	12.14	12.69	13.27	13.03	12.91	13.03	12.88	12.96	12.88	13.37	12.91	12.75
	23	12.89	12.60	12.75	12.55	12.56	12.59	12.37	12.38	12.78	12.75	12.44	12.31	12.65	12.40	11.84	12.17	12.08	12.06	12.28	12.26	12.64	12.67	12.73	12.76	12.66	12.31
	21	12.80	12.19	12.40	12.28	12.33	12.22	12.27	12.15	12.44	12.48	12.25	12.05	12.47	12.25	11.79	11.84	12.07	11.72	11.67	11.74	11.02	11.72	12.49	12.13	12.17	12.19

Extreme Mean Zero Crossing Period (in seconds) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 100 year return period (Northern Pacific Region), 3 day storm duration

		LONGITUDE																									
		E										W															
	0	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	16.60	17.02	16.64	16.93	17.20	17.41	17.62	17.32	18.09	18.28	17.29	16.95	17.32	17.76	17.94	17.37	17.14	16.73	17.16	17.31	17.06	16.60	16.65	16.61	16.81	16.57
	43	16.72	17.36	17.27	17.32	17.29	17.57	17.56	17.65	17.82	18.14	17.50	17.69	17.88	17.60	17.70	17.74	17.42	17.10	17.21	17.55	17.30	16.68	16.50	16.56	16.49	16.93
	41	16.99	17.10	17.04	17.39	17.28	17.70	18.06	17.61	17.64	17.47	17.14	17.40	18.03	17.09	17.40	17.20	17.16	16.65	17.18	17.09	16.83	16.56	16.44	16.60	16.62	16.52
	39	17.07	16.86	17.25	17.31	17.54	17.18	17.51	17.20	17.41	17.50	17.51	17.03	17.38	17.14	17.01	16.82	16.71	16.84	17.10	16.71	16.66	16.70	16.34	16.48	16.68	16.26
	37	17.00	16.65	17.23	16.88	17.24	16.98	17.14	16.92	16.77	17.00	17.00	16.77	16.64	16.68	16.83	16.86	16.28	16.79	16.90	16.49	16.36	16.46	15.93	16.11	16.17	16.00
	35	16.46	16.10	16.49	16.37	16.56	16.08	16.21	16.51	16.36	16.52	16.39	16.30	16.40	16.14	16.36	16.20	16.02	15.82	16.23	16.20	16.22	16.12	15.66	15.83	15.78	15.44
	33	15.80	15.99	15.83	15.75	15.60	15.41	15.69	15.64	16.01	15.65	15.77	15.71	15.92	15.63	15.60	15.68	15.85	14.89	15.52	15.44	15.39	15.60	15.33	15.08	15.35	15.26
	31	14.83	15.35	15.33	14.94	14.61	14.90	15.27	14.91	14.89	14.91	15.27	15.25	14.83	14.95	14.93	15.04	15.28	15.06	14.68	14.68	14.81	14.94	14.69	14.45	14.77	14.88
	29	14.36	14.70	14.39	14.46	13.90	14.23	14.69	14.51	14.03	14.26	14.34	14.58	13.99	14.49	14.55	14.53	14.02	14.53	14.08	14.22	13.97	14.65	14.22	14.23	14.01	14.29
	27	13.91	13.96	13.76	13.96	13.33	13.59	13.76	13.94	13.50	13.56	13.56	13.50	12.85	13.64	14.00	14.10	14.03	13.71	13.85	13.94	13.58	13.93	13.61	13.64	13.64	13.56
	25	13.43	13.34	13.18	13.38	13.11	13.14	12.93	13.23	13.33	13.25	13.11	13.16	13.05	12.73	12.36	12.94	13.54	13.30	13.18	13.29	13.14	13.22	13.13	13.65	13.17	13.01
	23	13.15	12.85	13.00	12.80	12.81	12.84	12.60	12.63	13.03	13.00	12.70	12.55	12.90	12.66	12.07	12.39	12.32	12.29	12.51	12.49	12.88	12.92	12.99	13.02	12.91	12.54
	21	13.05	12.42	12.64	12.53	12.56	12.45	12.50	12.39	12.67	12.73	12.48	12.28	12.72	12.48	12.01	12.06	12.30	11.94	11.87	11.95	11.22	11.94	12.75	12.36	12.41	12.41

Table A-12: Mean minimum wave length of extreme wave predicted using the Alves and Young's data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Mean minimum wave length (in meters) of extreme wave prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 50 year return period (Northern Pacific Region), 3 day storm duration

	LONGITUDE																										
	E										W															
LATITUDE (N)	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	178.00	228.99	175.00	202.00	219.99	222.99	240.99	219.99	243.99	249.99	216.99	213.99	222.99	231.99	246.99	225.99	225.99	184.00	196.00	234.99	199.00	196.00	196.00	199.00	193.00	178.00
43	199.00	243.99	225.99	228.99	222.99	234.99	222.99	240.99	228.99	249.99	228.99	222.99	234.99	240.99	237.99	237.99	222.99	213.99	219.99	237.99	234.99	190.00	169.00	181.00	184.00	199.00
41	225.99	205.00	208.00	237.99	231.99	234.99	249.99	240.99	249.99	231.99	222.99	213.99	246.99	219.99	222.99	216.99	213.99	190.00	216.99	213.99	208.00	184.00	181.00	181.00	190.00	184.00
39	216.99	208.00	222.99	228.99	231.99	222.99	240.99	216.99	222.99	246.99	234.99	222.99	228.99	210.99	210.99	193.00	190.00	205.00	222.99	184.00	202.00	196.00	166.00	184.00	187.00	169.00
37	199.00	193.00	216.99	208.00	213.99	213.99	213.99	216.99	210.99	196.00	213.99	193.00	178.00	196.00	202.00	213.99	163.00	178.00	202.00	190.00	178.00	181.00	160.00	169.00	169.00	175.00
35	181.00	160.00	175.00	178.00	178.00	163.00	166.00	190.00	187.00	184.00	175.00	181.00	169.00	169.00	169.00	169.00	163.00	163.00	169.00	172.00	166.00	163.00	160.00	160.00	163.00	160.00
33	163.00	163.00	160.00	160.00	160.00	160.00	160.00	160.00	163.00	160.00	163.00	160.00	163.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
31	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
29	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	157.66	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
27	155.33	160.00	160.00	157.66	153.00	157.66	155.33	160.00	153.00	153.00	160.00	146.00	129.66	157.66	157.66	160.00	157.66	157.66	153.00	160.00	150.66	160.00	160.00	155.33	160.00	155.33
25	155.33	146.00	146.00	153.00	141.33	141.33	136.66	148.33	148.33	141.33	134.33	148.33	125.00	129.66	97.00	132.00	157.66	146.00	143.66	153.00	129.66	146.00	141.33	150.66	132.00	134.33
23	139.00	132.00	148.33	122.66	120.33	132.00	113.33	108.66	125.00	125.00	115.66	106.33	125.00	118.00	92.33	94.66	99.33	94.66	99.33	104.00	118.00	125.00	134.33	127.33	129.66	101.66
21	139.00	99.33	108.66	104.00	104.00	99.33	115.66	97.00	111.00	115.66	104.00	92.33	108.66	94.66	90.00	90.00	97.00	90.00	90.00	92.33	90.00	90.00	111.00	101.66	97.00	101.66

Mean minimum wave length (in meters) of extreme wave prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 100 year return period (Northern Pacific Region), 3 day storm duration

	LONGITUDE																										
	E										W															
LATITUDE (N) 0	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
45	219.99	240.99	202.00	219.99	231.99	234.99	249.99	234.99	249.99	249.99	240.99	222.99	228.99	246.99	249.99	234.99	240.99	219.99	234.99	243.99	228.99	208.00	213.99	213.99	225.99	202.00
43	202.00	243.99	246.99	243.99	246.99	246.99	237.99	243.99	249.99	249.99	240.99	243.99	249.99	237.99	246.99	243.99	249.99	240.99	228.99	237.99	231.99	210.99	196.00	222.99	196.00	237.99
41	246.99	237.99	219.99	237.99	243.99	249.99	249.99	243.99	237.99	243.99	231.99	240.99	253.66	231.99	243.99	237.99	228.99	205.00	237.99	237.99	213.99	208.00	196.00	213.99	213.99	205.00
39	222.99	219.99	237.99	246.99	246.99	228.99	243.99	231.99	243.99	237.99	246.99	228.99	237.99	231.99	228.99	219.99	219.99	222.99	234.99	208.00	202.00	213.99	202.00	199.00	196.00	190.00
37	219.99	210.99	237.99	228.99	225.99	231.99	240.99	234.99	231.99	234.99	231.99	219.99	187.00	213.99	222.99	225.99	193.00	225.99	225.99	199.00	187.00	199.00	172.00	187.00	181.00	172.00
35	216.99	193.00	199.00	190.00	213.99	175.00	193.00	202.00	199.00	213.99	178.00	196.00	208.00	175.00	196.00	193.00	172.00	169.00	181.00	199.00	187.00	184.00	163.00	166.00	166.00	160.00
33	175.00	163.00	172.00	166.00	160.00	160.00	163.00	160.00	175.00	163.00	163.00	166.00	187.00	163.00	163.00	160.00	172.00	160.00	163.00	160.00	160.00	163.00	163.00	160.00	160.00	160.00
31	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
29	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
27	160.00	160.00	160.00	160.00	157.66	157.66	160.00	160.00	155.33	160.00	160.00	157.66	141.33	160.00	160.00	160.00	160.00	157.66	160.00	160.00	160.00	160.00	157.66	160.00	160.00	160.00
25	157.66	153.00	150.66	155.33	148.33	148.33	141.33	153.00	150.66	160.00	157.66	150.66	139.00	146.00	120.33	136.66	157.66	157.66	153.00	155.33	150.66	150.66	148.33	160.00	148.33	143.66
23	143.66	129.66	143.66	136.66	139.00	143.66	132.00	120.33	141.33	148.33	136.66	115.66	150.66	111.00	94.66	104.00	99.33	99.33	118.00	108.66	146.00	141.33	153.00	141.33	150.66	122.66
21	148.33	115.66	136.66	118.00	129.66	111.00	122.66	113.33	122.66	132.00	120.33	108.66	113.33	129.66	97.00	94.66	104.00	90.00	97.00	90.00	90.00	92.33	122.66	120.33	113.33	118.00

Table A-13: Extreme wave vertical velocity (RMS) predicted using the Alves and Young's data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Extreme wave RMS vertical velocity (in m/s) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 50 year return period (Northern Pacific Region), 3 day storm duration

		LONGITUDE																									
		E										W															
		161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	1.82	1.87	1.82	1.86	1.90	1.92	1.95	1.91	2.01	2.03	1.91	1.86	1.91	1.97	1.99	1.92	1.89	1.84	1.89	1.91	1.88	1.82	1.82	1.82	1.84	1.81
	43	1.83	1.91	1.91	1.91	1.90	1.94	1.94	1.95	1.98	2.02	1.93	1.96	1.98	1.95	1.96	1.97	1.92	1.88	1.90	1.94	1.91	1.83	1.80	1.81	1.80	1.86
	41	1.87	1.88	1.88	1.92	1.91	1.96	2.00	1.95	1.95	1.93	1.89	1.92	2.00	1.88	1.92	1.90	1.89	1.82	1.89	1.88	1.85	1.81	1.80	1.82	1.82	1.81
	39	1.88	1.85	1.90	1.91	1.94	1.89	1.93	1.90	1.92	1.93	1.94	1.87	1.92	1.89	1.87	1.85	1.83	1.85	1.88	1.83	1.82	1.83	1.78	1.80	1.83	1.77
	37	1.87	1.83	1.90	1.85	1.90	1.87	1.89	1.86	1.84	1.87	1.87	1.84	1.82	1.83	1.85	1.85	1.78	1.84	1.86	1.80	1.79	1.80	1.73	1.75	1.76	1.74
	35	1.80	1.75	1.80	1.79	1.81	1.75	1.77	1.80	1.79	1.81	1.79	1.78	1.79	1.76	1.79	1.76	1.74	1.72	1.77	1.76	1.77	1.75	1.69	1.72	1.71	1.67
	33	1.71	1.74	1.72	1.71	1.69	1.66	1.70	1.69	1.74	1.69	1.71	1.70	1.73	1.69	1.69	1.70	1.72	1.59	1.68	1.67	1.66	1.69	1.65	1.62	1.65	1.64
	31	1.59	1.65	1.65	1.60	1.56	1.60	1.64	1.60	1.59	1.59	1.64	1.64	1.58	1.60	1.60	1.61	1.64	1.62	1.57	1.57	1.58	1.60	1.57	1.53	1.58	1.59
	29	1.52	1.57	1.53	1.54	1.46	1.51	1.57	1.54	1.48	1.51	1.52	1.55	1.47	1.54	1.55	1.55	1.48	1.55	1.49	1.50	1.47	1.56	1.50	1.51	1.48	1.51
	27	1.46	1.47	1.44	1.47	1.39	1.42	1.44	1.47	1.41	1.42	1.42	1.41	1.32	1.43	1.48	1.49	1.48	1.44	1.46	1.47	1.42	1.46	1.42	1.43	1.43	1.42
	25	1.40	1.39	1.37	1.39	1.36	1.36	1.33	1.37	1.39	1.37	1.36	1.36	1.35	1.31	1.26	1.33	1.41	1.38	1.37	1.38	1.36	1.37	1.36	1.43	1.37	1.34
	23	1.36	1.32	1.34	1.31	1.32	1.32	1.29	1.29	1.35	1.34	1.30	1.28	1.33	1.29	1.21	1.26	1.25	1.24	1.28	1.27	1.33	1.33	1.34	1.34	1.33	1.28
	21	1.35	1.26	1.29	1.28	1.28	1.27	1.28	1.26	1.30	1.31	1.27	1.24	1.30	1.27	1.21	1.21	1.25	1.20	1.19	1.20	1.10	1.20	1.31	1.26	1.26	1.26

Extreme wave RMS vertical velocity (in m/s) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 100 year return period (Northern Pacific Region), 3 day storm duration

		LONGITUDE																									
		E										W															
	0	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	1.87	1.92	1.87	1.91	1.95	1.97	2.00	1.96	2.06	2.09	1.96	1.91	1.96	2.02	2.04	1.97	1.94	1.88	1.94	1.96	1.93	1.87	1.87	1.87	1.89	1.86
	43	1.88	1.97	1.96	1.96	1.96	2.00	1.99	2.00	2.03	2.07	1.99	2.01	2.04	2.00	2.01	2.02	1.98	1.93	1.95	1.99	1.96	1.88	1.85	1.86	1.85	1.91
	41	1.92	1.93	1.93	1.97	1.96	2.01	2.06	2.00	2.01	1.98	1.94	1.97	2.06	1.93	1.97	1.95	1.94	1.87	1.94	1.93	1.90	1.86	1.84	1.86	1.87	1.85
	39	1.93	1.90	1.95	1.96	1.99	1.94	1.99	1.95	1.97	1.99	1.99	1.92	1.97	1.94	1.92	1.89	1.88	1.90	1.93	1.88	1.87	1.88	1.83	1.85	1.88	1.82
	37	1.92	1.87	1.95	1.90	1.95	1.92	1.94	1.91	1.89	1.92	1.92	1.89	1.87	1.88	1.90	1.90	1.83	1.89	1.91	1.85	1.83	1.85	1.78	1.80	1.81	1.79
	35	1.85	1.80	1.85	1.84	1.86	1.80	1.81	1.85	1.83	1.85	1.84	1.83	1.84	1.80	1.83	1.81	1.79	1.76	1.82	1.81	1.82	1.80	1.74	1.76	1.75	1.71
	33	1.76	1.78	1.76	1.75	1.73	1.71	1.74	1.74	1.79	1.74	1.76	1.75	1.78	1.74	1.73	1.74	1.77	1.64	1.72	1.71	1.71	1.73	1.70	1.66	1.70	1.69
	31	1.63	1.70	1.70	1.64	1.60	1.64	1.69	1.64	1.64	1.64	1.69	1.69	1.63	1.64	1.64	1.66	1.69	1.66	1.61	1.61	1.62	1.64	1.61	1.58	1.62	1.63
	29	1.56	1.61	1.57	1.58	1.50	1.55	1.61	1.59	1.52	1.55	1.56	1.59	1.51	1.58	1.59	1.59	1.52	1.59	1.53	1.54	1.51	1.60	1.55	1.55	1.52	1.55
	27	1.50	1.51	1.48	1.51	1.42	1.46	1.48	1.51	1.45	1.45	1.45	1.45	1.36	1.47	1.52	1.53	1.52	1.47	1.49	1.51	1.46	1.50	1.46	1.47	1.47	1.45
	25	1.44	1.42	1.40	1.43	1.39	1.40	1.37	1.41	1.42	1.41	1.39	1.40	1.38	1.34	1.29	1.37	1.45	1.42	1.40	1.42	1.40	1.41	1.40	1.47	1.40	1.38
	23	1.40	1.36	1.38	1.35	1.35	1.35	1.32	1.33	1.38	1.38	1.33	1.31	1.36	1.33	1.25	1.29	1.28	1.28	1.31	1.31	1.36	1.37	1.38	1.38	1.37	1.31
	21	1.38	1.30	1.33	1.31	1.32	1.30	1.31	1.29	1.33	1.34	1.31	1.28	1.34	1.31	1.24	1.25	1.28	1.23	1.22	1.23	1.12	1.23	1.34	1.29	1.29	1.30

Table A-14: Extreme wave vertical acceleration (RMS) predicted using the Alves and Young's data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Extreme wave RMS vertical acceleration (in m/s^2) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 50 year return period (Northern Pacific Region), 3 day storm duration																											
		LONGITUDE																									
		E										W															
		161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	0.98	0.99	0.98	0.99	1.00	1.00	1.01	1.00	1.02	1.02	1.00	0.99	1.00	1.01	1.02	1.00	1.00	0.99	1.00	1.00	0.99	0.98	0.98	0.98	0.99	0.98
	43	0.99	1.00	1.00	1.00	1.00	1.01	1.01	1.01	1.01	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.01	1.00	0.98	0.98	0.98	0.98	0.99
	41	0.99	1.00	0.99	1.00	1.00	1.01	1.02	1.01	1.01	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.00	0.98	1.00	1.00	0.99	0.98	0.98	0.98	0.98	0.98
	39	0.99	0.99	1.00	1.00	1.01	1.00	1.01	1.00	1.00	1.01	1.01	0.99	1.00	1.00	0.99	0.99	0.99	0.99	1.00	0.99	0.98	0.99	0.98	0.98	0.98	0.97
	37	0.99	0.98	1.00	0.99	1.00	0.99	1.00	0.99	0.99	0.99	0.99	0.99	0.98	0.99	0.99	0.99	0.97	0.99	0.99	0.98	0.98	0.98	0.96	0.97	0.97	0.97
	35	0.98	0.97	0.98	0.98	0.98	0.97	0.97	0.98	0.98	0.98	0.98	0.97	0.98	0.97	0.98	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.96	0.96	0.96	0.95
	33	0.96	0.97	0.96	0.96	0.95	0.95	0.96	0.96	0.97	0.96	0.96	0.96	0.96	0.96	0.95	0.96	0.96	0.93	0.95	0.95	0.95	0.95	0.95	0.94	0.95	0.94
	31	0.93	0.95	0.95	0.94	0.92	0.93	0.95	0.93	0.93	0.93	0.94	0.94	0.93	0.94	0.93	0.94	0.95	0.94	0.93	0.93	0.93	0.94	0.93	0.92	0.93	0.93
	29	0.92	0.93	0.92	0.92	0.90	0.91	0.93	0.92	0.91	0.91	0.92	0.92	0.90	0.92	0.92	0.92	0.91	0.92	0.91	0.91	0.90	0.93	0.91	0.91	0.90	0.91
	27	0.90	0.90	0.90	0.90	0.88	0.89	0.90	0.90	0.89	0.89	0.89	0.89	0.86	0.89	0.90	0.91	0.91	0.89	0.90	0.90	0.89	0.90	0.89	0.89	0.89	0.89
	25	0.88	0.88	0.87	0.88	0.87	0.87	0.86	0.88	0.88	0.88	0.87	0.87	0.87	0.86	0.84	0.87	0.89	0.88	0.87	0.88	0.87	0.88	0.87	0.89	0.87	0.87
	23	0.87	0.86	0.87	0.86	0.86	0.86	0.85	0.85	0.87	0.87	0.86	0.85	0.86	0.85	0.83	0.84	0.84	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.86	0.85
	21	0.87	0.84	0.85	0.85	0.85	0.85	0.85	0.84	0.85	0.86	0.85	0.84	0.86	0.85	0.83	0.83	0.84	0.82	0.82	0.82	0.79	0.82	0.86	0.84	0.84	0.84

Extreme wave RMS vertical acceleration (in m/s^2) prediction using the Alves and Young's extreme Hs data (FT1) and wave simulation (Pierson-Moskowitz), 2 deg x 2 deg grid, 100 year return period (Northern Pacific Region), 3 day storm duration																											
		LONGITUDE																									
		E										W															
	0	161	163	165	167	169	171	173	175	177	179	179	177	175	173	171	169	167	165	163	161	159	157	155	153	151	149
LATITUDE (N)	45	0.99	1.00	0.99	1.00	1.01	1.01	1.02	1.01	1.03	1.03	1.01	1.00	1.01	1.02	1.03	1.01	1.01	1.00	1.01	1.01	1.00	0.99	0.99	0.99	1.00	0.99
	43	1.00	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.03	1.02	1.02	1.02	1.02	1.02	1.02	1.01	1.00	1.01	1.02	1.01	0.99	0.99	0.99	0.99	1.00
	41	1.00	1.01	1.00	1.01	1.01	1.02	1.03	1.02	1.02	1.01	1.01	1.01	1.03	1.00	1.01	1.01	1.01	0.99	1.01	1.00	1.00	0.99	0.99	0.99	0.99	0.99
	39	1.00	1.00	1.01	1.01	1.02	1.01	1.02	1.01	1.01	1.01	1.02	1.00	1.01	1.01	1.00	1.00	1.00	1.00	1.01	0.99	0.99	0.99	0.99	0.99	0.99	0.98
	37	1.00	0.99	1.01	1.00	1.01	1.00	1.01	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.98	1.00	1.00	0.99	0.99	0.99	0.97	0.98	0.98	0.98
	35	0.99	0.98	0.99	0.99	0.99	0.98	0.98	0.99	0.99	0.99	0.99	0.98	0.99	0.98	0.99	0.98	0.98	0.97	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.96
	33	0.97	0.98	0.97	0.97	0.96	0.96	0.97	0.97	0.98	0.97	0.97	0.97	0.97	0.97	0.96	0.97	0.97	0.94	0.96	0.96	0.96	0.96	0.96	0.95	0.96	0.95
	31	0.94	0.96	0.96	0.95	0.93	0.94	0.96	0.94	0.94	0.94	0.95	0.95	0.94	0.95	0.94	0.95	0.96	0.95	0.94	0.94	0.94	0.95	0.94	0.93	0.94	0.94
	29	0.93	0.94	0.93	0.93	0.91	0.92	0.94	0.93	0.92	0.92	0.93	0.93	0.91	0.93	0.93	0.93	0.92	0.93	0.92	0.92	0.91	0.94	0.92	0.92	0.92	0.92
	27	0.91	0.91	0.91	0.91	0.89	0.90	0.91	0.91	0.90	0.90	0.90	0.90	0.87	0.90	0.91	0.92	0.92	0.90	0.91	0.91	0.90	0.91	0.90	0.90	0.90	0.90
	25	0.89	0.89	0.88	0.89	0.88	0.88	0.88	0.89	0.89	0.89	0.88	0.88	0.88	0.87	0.85	0.88	0.90	0.89	0.88	0.89	0.88	0.89	0.88	0.90	0.88	0.88
	23	0.88	0.87	0.88	0.87	0.87	0.87	0.86	0.86	0.88	0.88	0.87	0.86	0.87	0.86	0.84	0.85	0.85	0.85	0.86	0.86	0.87	0.87	0.88	0.88	0.87	0.86
	21	0.88	0.85	0.86	0.86	0.86	0.86	0.86	0.85	0.86	0.87	0.86	0.85	0.87	0.86	0.84	0.84	0.85	0.83	0.83	0.83	0.80	0.83	0.87	0.85	0.85	0.85

Appendix B: North Atlantic (37^o-57^o N, 19^o-49^o W)

- Table B-1: Extreme significant wave heights predicted by Alves and Young
- Table B-2: Extreme wave heights predicted using FT1/IDM for significant wave height, FT1 for mean wave period and the Bretschneider spectrum for short term order statistics
- Table B-3: Extreme wave heights predicted using FT1/IDM for significant wave height, FT1 for mean wave period and the Ochi spectrum for short term order statistics
- Table B-4: Extreme wave heights predicted using FT1/IDM for significant wave height, W2P for mean wave period and the Bretschneider spectrum for short term order statistics
- Table B-5: Extreme wave heights predicted using FT1/IDM for significant wave height, W2P for mean wave period and the Ochi spectrum for short term order statistics
- Table B-6: Extreme wave heights predicted using FT1/IDM for significant wave height, average of FT1 & W2P for mean wave period and the Bretschneider spectrum for short term order statistics
- Table B-7: Extreme wave heights predicted using FT1/IDM for significant wave height, average of FT1 & W2P for mean wave period and the Ochi spectrum for short term order statistics
- Table B-8: Extreme wave amplitudes (RMS) predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 hrs) using the Pierson-Moskowitz spectrum
- Table B-9: Extreme wave amplitudes (RMS) predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table B-10: Extreme wave heights predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table B-11: Extreme wave zero-crossing period predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table B-12: Mean minimum wave length of extreme wave predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table B-13: Extreme wave velocity (RMS) predicted using the Alves and Young's extreme H_s data (FT1/IDM) and a wave simulation (3 days) using the Pierson-Moskowitz spectrum
- Table B-14: Extreme wave acceleration (RMS) predicted using the Alves and Young's data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Table B-1: Extreme significant wave heights predicted by Alves and Young (Atlas of the Oceans)

Extreme Hs (in meters) prediction by I.R. Young & J.H.G.M. Alves using FT1 / IDM, 2 deg x 2 deg grid, 50 year return period (Northern Pacific Region)

	LONGITUDE W															
LATITUDE (N)	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	19.4	19.65	21.64	22.26	22.48	22.14	23.51	23.55	22.5	22.43	23.96	24.62	22.62	22.13	22.7	23.3
55	20.12	20.1	20.93	21.04	20.61	21.42	22.74	23.08	23.32	21.4	22.65	23.29	22.24	22.15	22.89	23.89
53	18.78	19.55	19.85	21	20.97	22.24	22.6	21.85	22.53	22.84	22.52	21.3	21.35	22.42	22.74	22.5
51	17.69	18.75	20.43	21.33	21.03	21.25	21.93	22.45	22.9	22.83	22.32	20.33	20.98	22.04	22.05	20.71
49	16.83	17.19	18.75	19.34	20.4	21.87	21.89	22.32	22	21.57	20.99	20.91	20.63	20.5	19.33	19.9
47	15.68	15.9	17.47	18.59	20.27	20.83	21.66	21.55	20.54	20.74	20.19	19.96	19.05	19.44	19.65	19.07
45	14.5	15.9	17.33	18.81	19.78	19.86	20.87	19.62	19.7	19.75	18.81	18.64	17.91	18.48	18.73	18.39
43	14.9	16.62	16.6	17.81	18.25	18.29	19.03	17.95	18.28	18.65	18.64	17.25	16.5	16.84	17.75	17.28
41	16.92	16.93	16.41	17.77	16.93	17.12	17.54	17.27	16.85	17.71	17.1	15.66	15.7	15.56	15.59	15.58
39	16.47	16.22	16.17	16	15.74	15.58	15.48	15.92	16.07	15.11	14.62	13.34	14.48	14.06	13.48	14.07
37	15.4	15.16	15.49	15.35	14.9	14.12	14.09	15.45	14.75	13.81	12.53	12.15	11.45	12.34	12.2	12.74

Extreme Hs (in meters) prediction by I.R. Young & J.H.G.M. Alves using FT1 / IDM, 2 deg x 2 deg grid, 100 year return period (Northern Pacific Region)

	LONGITUDE W															
LATITUDE (N)	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	20.39	20.64	22.74	23.39	23.62	23.26	24.71	24.75	23.64	23.56	25.19	25.88	23.77	23.24	23.85	24.48
55	21.14	21.12	21.98	22.1	21.65	22.5	23.89	24.25	24.51	22.48	23.8	24.48	23.36	23.27	24.05	25.11
53	19.72	20.54	20.84	22.05	22.02	23.36	23.74	22.95	23.67	24	23.66	22.37	22.42	23.56	23.9	23.65
51	18.59	19.69	21.47	22.41	22.08	22.31	23.03	23.58	24.06	23.98	23.45	21.35	22.03	23.16	23.17	21.75
49	17.68	18.05	19.69	20.31	21.42	22.98	22.99	23.45	23.11	22.65	22.05	21.96	21.67	21.54	20.3	20.91
47	16.46	16.69	18.34	19.52	21.29	21.88	22.75	22.64	21.57	21.78	21.21	20.97	20.01	20.41	20.65	20.04
45	15.22	16.7	18.19	19.75	20.78	20.86	21.93	20.61	20.69	20.75	19.75	19.57	18.81	19.41	19.68	19.32
43	15.65	17.46	17.42	18.7	19.16	19.21	19.99	18.85	19.2	19.59	19.58	18.11	17.33	17.69	18.65	18.15
41	17.77	17.78	17.23	18.67	17.78	17.98	18.43	18.13	17.7	18.61	17.97	16.45	16.48	16.33	16.38	16.36
39	17.29	17.04	16.99	16.8	16.53	16.37	16.26	16.72	16.88	15.87	15.36	14.01	15.2	14.76	14.15	14.77
37	16.17	15.92	16.27	16.13	15.65	14.82	14.8	16.24	15.49	14.5	13.16	12.76	12.02	12.95	12.8	13.37

Extreme Hs (in meters) prediction by I.R. Young & J.H.G.M. Alves using FT1 / IDM, 4 deg x 4 deg grid, 50 year return period (Northern Pacific Region)

	LONGITUDE W															
LATITUDE (N)	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	18.88	19.83	20.89	21.63	22.08	22.56	22.62	22.97	23.17	23.11	23.05	23.57	23.04	22.5	22.66	22.7
55	18.94	20.13	20.48	21.07	21.13	21.92	22.58	22.77	22.32	22.88	22.64	22.87	22.09	22.32	22.97	22.76
53	18.63	19.64	20.43	20.42	20.83	21.48	21.95	22.55	22.75	22.25	22.27	21.99	22.04	22.05	22.37	22.59
51	18.19	18.53	19.66	20.58	20.91	21.52	22.03	21.96	22.54	22.5	22.01	21.06	20.97	21.29	21.65	21.82
49	16.49	17.79	18.69	19.97	20.71	21.08	21.87	22.16	21.83	21.75	21.29	20.3	20.45	20.48	20.48	19.86
47	15.69	16.59	17.53	18.99	19.86	20.55	21.25	20.9	21.05	20.59	20.04	19.54	19.22	19.36	19.3	19.5
45	15.27	15.68	16.63	18.22	19	19.77	19.84	20.05	19.44	19.7	19.24	18.34	18.18	18.22	18.28	18.26
43	15.75	16.05	17.08	18	18.23	18.75	18.94	18.52	18.5	18.59	18.16	17.17	16.72	17.02	17.02	16.93
41	16.78	16.55	16.83	16.85	17.11	17.12	17.18	17.12	17.05	16.98	16.62	15.88	15.54	15.69	15.44	15.39
39	16.64	16.35	16.15	15.94	15.91	15.69	16.04	15.87	15.72	15.44	14.13	13.74	13.93	14.16	14.05	13.66
37	15.35	15.68	15.34	15.02	14.53	14.56	14.77	14.93	14.95	14.01	12.75	12.03	11.92	12.41	12.38	12.64

Extreme Hs (in meters) prediction by I.R. Young & J.H.G.M. Alves using FT1 / IDM, 4 deg x 4 deg grid, 100 year return period (Northern Pacific Region)

	LONGITUDE W															
LATITUDE (N)	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	19.84	20.83	21.94	22.73	23.2	23.7	23.76	24.13	24.35	24.29	24.22	24.77	24.21	23.64	23.81	23.85
55	19.9	21.15	21.51	22.14	22.19	23.03	23.73	23.93	23.45	24.04	23.79	24.03	23.2	23.45	24.13	23.92
53	19.57	20.63	21.46	21.45	21.87	22.56	23.05	23.69	23.91	23.38	23.39	23.1	23.16	23.17	23.51	23.74
51	19.11	19.46	20.64	21.61	21.96	22.6	23.14	23.06	23.68	23.64	23.12	22.12	22.03	22.37	22.75	22.93
49	17.33	18.68	19.63	20.97	21.75	22.14	22.97	23.27	22.93	22.85	22.36	21.32	21.48	21.51	21.52	20.87
47	16.48	17.42	18.4	19.94	20.85	21.58	22.32	21.95	22.11	21.62	21.05	20.52	20.18	20.33	20.27	20.49
45	16.03	16.46	17.45	19.13	19.96	20.76	20.84	21.06	20.41	20.69	20.21	19.26	19.09	19.14	19.21	19.18
43	16.54	16.86	17.93	18.9	19.15	19.69	19.89	19.46	19.43	19.53	19.08	18.03	17.56	17.87	17.88	17.78
41	17.63	17.38	17.68	17.69	17.97	17.98	18.04	17.98	17.91	17.84	17.46	16.68	16.32	16.47	16.22	16.16
39	17.49	17.17	16.96	16.73	16.7	16.48	16.84	16.67	16.51	16.22	14.84	14.43	14.63	14.86	14.75	14.34
37	16.13	16.47	16.12	15.77	15.25	15.29	15.52	15.68	15.71	14.72	13.38	12.63	12.51	13.03	12.99	13.26

Table B-2: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, FT1 for mean wave period and the Bretschneider spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, FT1 for Tm, 2 x 2 grid, 50 year return period

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	34.63	35.07	38.51	39.44	39.83	39.24	41.6	41.67	39.67	39.4	42.09	43.23	39.73	38.87	39.9	41.09
	55	35.86	35.82	37.23	37.31	36.55	37.98	40.2	40.8	41.15	37.66	39.86	40.99	39.2	39.04	40.27	42.06
	53	33.47	34.84	35.31	37.24	37.19	39.43	39.96	38.63	39.76	40.19	39.63	37.49	37.63	39.52	40.01	39.62
	51	31.63	33.52	36.43	37.95	37.41	37.69	38.74	39.65	40.44	40.3	39.4	35.81	36.89	38.75	38.83	36.3
	49	30	30.64	33.38	34.33	36.21	38.76	38.65	39.41	38.87	38.02	37	36.77	36.31	36.08	34.02	34.95
	47	27.95	28.34	31.1	32.99	35.98	36.92	38.25	38.05	36.29	36.56	35.59	35.1	33.53	34.22	34.58	33.49
	45	25.86	28.36	30.89	33.45	35.17	35.24	36.97	34.75	34.88	34.85	33.2	32.84	31.53	32.53	32.95	32.34
	43	26.53	29.59	29.61	31.67	32.45	32.44	33.66	31.75	32.39	32.92	32.9	30.46	29.12	29.72	31.23	30.41
	41	30.12	30.14	29.27	31.6	30.11	30.36	31.02	30.54	29.86	31.26	30.19	27.65	27.71	27.46	27.43	27.41
	39	29.27	28.83	28.73	28.42	27.96	27.6	27.34	28.11	28.42	26.7	25.83	23.53	25.56	24.82	23.71	24.69
	37	27.36	26.93	27.53	27.25	26.45	25.03	24.92	27.33	26.15	24.44	22.18	21.44	20.2	21.77	21.45	22.33

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, FT1 for Tm, 2 x 2 grid, 100 year return period

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	36.29	36.74	40.36	41.32	41.73	41.11	43.59	43.66	41.56	41.26	44.11	45.31	41.62	40.7	41.79	43.05
	55	37.57	37.54	38.99	39.08	38.28	39.78	42.11	42.75	43.12	39.44	41.75	42.96	41.05	40.89	42.19	44.08
	53	35.05	36.5	36.97	38.99	38.94	41.3	41.85	40.46	41.65	42.1	41.51	39.26	39.4	41.4	41.93	41.52
	51	33.15	35.11	38.18	39.76	39.17	39.46	40.56	41.53	42.36	42.21	41.28	37.5	38.62	40.6	40.68	38
	49	31.43	32.08	34.96	35.95	37.91	40.61	40.48	41.29	40.72	39.81	38.75	38.5	38.03	37.8	35.62	36.61
	47	29.26	29.67	32.56	34.55	37.68	38.67	40.05	39.86	38	38.28	37.28	36.77	35.11	35.82	36.23	35.08
	45	27.07	29.7	32.34	35.02	36.85	36.91	38.73	36.4	36.53	36.51	34.75	34.38	33.01	34.06	34.51	33.87
	43	27.78	31	30.99	33.16	33.98	33.97	35.25	33.24	33.93	34.48	34.46	31.88	30.5	31.13	32.72	31.84
	41	31.55	31.57	30.65	33.11	31.53	31.8	32.5	31.97	31.28	32.75	31.63	28.96	29	28.74	28.74	28.7
	39	30.64	30.2	30.1	29.76	29.28	28.91	28.63	29.44	29.76	27.96	27.06	24.64	26.75	25.98	24.82	25.84
	37	28.64	28.2	28.83	28.55	27.7	26.19	26.1	28.64	27.38	25.59	23.23	22.45	21.15	22.78	22.43	23.36

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, FT1 for Tm, 4 x 4 grid, 50 year return period

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	33.7	35.39	37.18	38.32	39.12	39.99	40.02	40.64	40.85	40.6	40.49	41.39	40.47	39.52	39.83	40.03
	55	33.76	35.88	36.43	37.36	37.47	38.87	39.92	40.26	39.39	40.26	39.84	40.25	38.93	39.34	40.41	40.07
	53	33.2	35	36.34	36.21	36.94	38.09	38.81	39.87	40.15	39.15	39.19	38.7	38.85	38.86	39.36	39.78
	51	32.52	33.13	35.05	36.61	37.2	38.17	38.91	38.79	39.8	39.72	38.86	37.1	36.87	37.43	38.13	38.24
	49	29.39	31.71	33.27	35.44	36.76	37.36	38.62	39.13	38.57	38.34	37.53	35.7	35.99	36.05	36.04	34.88
	47	27.97	29.57	31.21	33.7	35.25	36.42	37.52	36.9	37.19	36.29	35.32	34.36	33.83	34.08	33.96	34.24
	45	27.23	27.96	29.64	32.4	33.79	35.08	35.14	35.51	34.42	34.77	33.95	32.32	32	32.07	32.16	32.11
	43	28.04	28.57	30.46	32.01	32.42	33.25	33.5	32.75	32.78	32.82	32.06	30.32	29.51	30.04	29.95	29.79
	41	29.87	29.46	30.02	29.96	30.43	30.36	30.38	30.28	30.21	29.97	29.34	28.04	27.43	27.69	27.17	27.08
	39	29.57	29.06	28.69	28.32	28.26	27.79	28.32	28.02	27.8	27.28	24.97	24.23	24.59	25	24.72	23.97
	37	27.27	27.85	27.26	26.66	25.79	25.81	26.13	26.41	26.5	24.8	22.57	21.22	21.03	21.9	21.76	22.16

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, FT1 for Tm, 4 x 4 grid, 100 year return period

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	35.31	37.08	38.94	40.16	40.99	41.89	41.92	42.57	42.81	42.54	42.42	43.37	42.39	41.4	41.72	41.94
	55	35.37	37.59	38.16	39.15	39.24	40.72	41.83	42.18	41.26	42.17	41.74	42.17	40.77	41.21	42.33	41.99
	53	34.78	36.66	38.07	37.93	38.67	39.89	40.63	41.76	42.07	41.02	41.03	40.54	40.7	40.72	41.24	41.68
	51	34.08	34.7	36.7	38.34	38.96	39.97	40.75	40.61	41.69	41.61	40.7	38.85	38.62	39.21	39.95	40.06
	49	30.81	33.2	34.85	37.11	38.49	39.13	40.44	40.97	40.4	40.16	39.3	37.38	37.69	37.75	37.76	36.54
	47	29.29	30.97	32.67	35.29	36.9	38.14	39.3	38.64	38.95	38	37	35.98	35.41	35.68	35.56	35.87
	45	28.51	29.28	31.02	33.92	35.4	36.74	36.81	37.2	36.03	36.41	35.56	33.84	33.5	33.59	33.69	33.63
	43	29.36	29.93	31.89	33.52	33.96	34.82	35.08	34.32	34.33	34.37	33.58	31.74	30.9	31.45	31.37	31.19
	41	31.3	30.86	31.45	31.37	31.87	31.8	31.81	31.71	31.65	31.4	30.73	29.36	28.72	28.98	28.45	28.35
	39	30.99	30.43	30.04	29.64	29.58	29.11	29.65	29.35	29.11	28.57	26.14	25.38	25.75	26.15	25.87	25.08
	37	28.57	29.17	28.56	27.92	27	27.02	27.37	27.66	27.77	25.98	23.62	22.22	22.01	22.92	22.76	23.17

Table B-3: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, FT1 for mean wave period and the Ochi spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, FT1 for Tm, 2 x 2 grid, 50 year return period

	Longitude W															
LATITUDE (N)	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	32.66	33.1	36.33	36.98	37.37	36.82	39.01	39.08	36.94	36.47	39.06	40.16	36.78	35.95	36.98	38.33
55	33.8	33.76	35.04	34.95	34.21	35.6	37.6	38.19	38.42	34.88	37	38.12	36.46	36.3	37.4	39.18
53	31.45	32.8	33.16	34.88	34.83	37.02	37.36	36.07	37.07	37.32	36.78	34.73	34.94	36.76	37.15	36.81
51	29.8	31.67	34.38	35.76	35.23	35.33	36.13	37.02	37.76	37.62	36.75	33.15	34.09	35.89	36.06	33.38
49	28.06	28.69	31.31	32.08	33.92	36.34	36.03	36.76	36.28	35.32	34.33	34	33.6	33.38	31.38	32.17
47	26.07	26.45	29.08	30.79	33.69	34.54	35.63	35.44	33.77	33.91	32.97	32.39	30.92	31.58	31.92	30.78
45	24.06	26.49	28.94	31.32	33.01	32.97	34.55	32.4	32.5	32.32	30.72	30.31	29.01	29.97	30.34	29.74
43	24.64	27.61	27.71	29.59	30.35	30.21	31.26	29.42	30.13	30.47	30.45	28.1	26.81	27.38	28.71	27.92
41	28.13	28.15	27.38	29.52	28.06	28.19	28.72	28.26	27.68	28.87	27.84	25.41	25.46	25.22	25.08	25.07
39	27.23	26.8	26.68	26.39	25.94	25.49	25.12	25.86	26.21	24.53	23.7	21.46	23.41	22.71	21.55	22.4
37	25.36	24.95	25.54	25.23	24.46	23.04	22.88	25.18	24.12	22.44	20.28	19.49	18.33	19.81	19.4	20.15

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, FT1 for Tm, 2 x 2 grid, 100 year return period

	Longitude W															
LATITUDE (N)	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	34.16	34.59	37.98	38.65	39.05	38.48	40.79	40.86	38.6	38.09	40.84	41.98	38.44	37.55	38.64	40.06
55	35.33	35.29	36.61	36.52	35.75	37.2	39.3	39.91	40.16	36.44	38.67	39.85	38.09	37.94	39.08	40.96
53	32.86	34.28	34.63	36.44	36.38	38.69	39.04	37.68	38.73	39.01	38.43	36.28	36.49	38.43	38.83	38.48
51	31.17	33.09	35.95	37.38	36.8	36.9	37.73	38.67	39.47	39.31	38.4	34.63	35.6	37.51	37.68	34.85
49	29.33	29.97	32.71	33.52	35.43	37.98	37.63	38.42	37.9	36.89	35.87	35.51	35.1	34.88	32.77	33.62
47	27.23	27.62	30.37	32.16	35.21	36.09	37.22	37.04	35.28	35.42	34.45	33.84	32.3	32.98	33.36	32.17
45	25.13	27.68	30.22	32.72	34.5	34.45	36.12	33.86	33.95	33.77	32.08	31.65	30.3	31.3	31.7	31.07
43	25.75	28.86	28.93	30.91	31.7	31.56	32.67	30.73	31.49	31.83	31.81	29.35	28.01	28.61	30	29.16
41	29.39	29.41	28.6	30.86	29.32	29.46	30.02	29.51	28.93	30.18	29.1	26.56	26.58	26.33	26.21	26.18
39	28.44	28.01	27.89	27.57	27.11	26.64	26.24	27.02	27.38	25.63	24.77	22.42	24.45	23.71	22.5	23.38
37	26.49	26.06	26.68	26.38	25.56	24.06	23.9	26.33	25.21	23.44	21.19	20.36	19.14	20.68	20.24	21.03

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, FT1 for Tm, 4 x 4 grid, 50 year return period

	Longitude W															
LATITUDE (N)	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	31.75	33.42	35.02	35.89	36.67	37.55	37.47	38.08	38.08	37.62	37.52	38.37	37.49	36.58	36.92	37.3
55	31.73	33.82	34.26	35.01	35.11	36.47	37.33	37.66	36.71	37.39	36.98	37.4	36.2	36.59	37.54	37.25
53	31.19	32.96	34.17	33.88	34.59	35.7	36.24	37.28	37.44	36.32	36.36	35.9	36.12	36.13	36.52	36.96
51	30.68	31.28	33.03	34.45	35.02	35.8	36.3	36.18	37.15	37.06	36.21	34.39	34.08	34.62	35.37	35.24
49	27.47	29.74	31.2	33.17	34.46	34.97	35.99	36.49	35.98	35.63	34.84	32.97	33.29	33.34	33.32	32.11
47	26.08	27.65	29.19	31.48	32.98	34.05	34.93	34.33	34.64	33.65	32.72	31.68	31.21	31.45	31.33	31.5
45	25.39	26.1	27.72	30.3	31.65	32.81	32.78	33.14	32.05	32.23	31.45	29.8	29.46	29.53	29.58	29.52
43	26.11	26.62	28.54	29.92	30.32	31	31.11	30.39	30.51	30.36	29.63	27.97	27.18	27.69	27.48	27.33
41	27.89	27.49	28.11	27.93	28.38	28.19	28.1	28	28.02	27.63	27.02	25.78	25.19	25.44	24.83	24.75
39	27.52	27.02	26.65	26.29	26.24	25.67	26.06	25.78	25.61	25.08	22.87	22.13	22.49	22.88	22.5	21.72
37	25.27	25.84	25.28	24.67	23.83	23.79	24.03	24.3	24.47	22.78	20.65	19.29	19.11	19.92	19.7	19.99

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, FT1 for Tm, 4 x 4 grid, 100 year return period

	Longitude W															
LATITUDE (N)	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	33.19	34.93	36.59	37.52	38.33	39.24	39.15	39.79	39.81	39.32	39.21	40.1	39.18	38.22	38.58	38.98
55	33.17	35.35	35.79	36.59	36.68	38.12	39.02	39.36	38.36	39.07	38.65	39.08	37.82	38.24	39.22	38.94
53	32.6	34.44	35.71	35.4	36.13	37.31	37.86	38.95	39.14	37.96	37.97	37.51	37.75	37.77	38.17	38.63
51	32.08	32.69	34.5	35.99	36.6	37.4	37.92	37.79	38.82	38.73	37.84	35.93	35.6	36.18	36.97	36.82
49	28.73	31.06	32.61	34.65	36	36.53	37.6	38.11	37.6	37.23	36.4	34.43	34.78	34.83	34.83	33.55
47	27.26	28.88	30.48	32.88	34.45	35.57	36.49	35.86	36.2	35.14	34.18	33.09	32.59	32.84	32.72	32.92
45	26.52	27.27	28.94	31.65	33.08	34.28	34.25	34.63	33.48	33.67	32.86	31.13	30.77	30.85	30.91	30.84
43	27.28	27.83	29.82	31.25	31.68	32.38	32.5	31.77	31.88	31.73	30.97	29.21	28.39	28.92	28.71	28.55
41	29.15	28.72	29.38	29.17	29.65	29.46	29.36	29.25	29.29	28.88	28.24	26.94	26.31	26.56	25.95	25.85
39	28.78	28.23	27.84	27.45	27.4	26.83	27.22	26.93	26.76	26.22	23.9	23.12	23.5	23.88	23.49	22.68
37	26.42	27	26.43	25.76	24.88	24.85	25.11	25.38	25.58	23.81	21.56	20.14	19.95	20.81	20.56	20.85

Table B-4: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, W2P for mean wave period and the Bretschneider spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, W2P for Tm, 2 x 2 grid, 50 year return period

LATITUDE (N) \ Longitude W	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	35.56	36.02	39.59	40.57	40.97	40.35	42.78	42.86	40.83	40.57	43.34	44.51	40.92	40.03	41.08	42.26
55	36.86	36.82	38.27	38.35	37.57	39.05	41.36	41.98	42.34	38.78	41.04	42.19	40.33	40.17	41.45	43.3
53	34.4	35.81	36.29	38.28	38.22	40.54	41.11	39.74	40.91	41.39	40.81	38.59	38.72	40.66	41.18	40.78
51	32.46	34.41	37.4	38.99	38.44	38.75	39.86	40.81	41.6	41.44	40.52	36.86	37.99	39.91	39.97	37.4
49	30.82	31.48	34.31	35.29	37.22	39.86	39.78	40.56	39.99	39.13	38.08	37.88	37.36	37.13	35.01	36.01
47	28.71	29.12	31.96	33.92	36.98	37.96	39.36	39.16	37.33	37.62	36.63	36.16	34.5	35.21	35.59	34.51
45	26.56	29.12	31.74	34.38	36.15	36.23	38.03	35.75	35.86	35.87	34.16	33.81	32.45	33.49	33.93	33.3
43	27.27	30.42	30.42	32.55	33.35	33.36	34.64	32.68	33.31	33.89	33.87	31.33	29.96	30.58	32.16	31.3
41	30.97	30.99	30.07	32.47	30.94	31.22	31.93	31.44	30.7	32.18	31.07	28.44	28.51	28.25	28.24	28.22
39	30.09	29.63	29.54	29.21	28.74	28.4	28.14	28.94	29.22	27.45	26.56	24.21	26.28	25.52	24.4	25.43
37	28.13	27.69	28.31	28.02	27.2	25.74	25.65	28.12	26.88	25.13	22.8	22.05	20.78	22.4	22.08	23

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, W2P for Tm, 2 x 2 grid, 100 year return period

LATITUDE (N) \ Longitude W	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	37.35	37.8	41.56	42.59	43.01	42.35	44.93	45	42.85	42.57	45.52	46.74	42.95	41.99	43.12	44.36
55	38.69	38.65	40.15	40.25	39.43	40.98	43.42	44.07	44.46	40.69	43.08	44.31	42.33	42.16	43.51	45.47
53	36.09	37.59	38.07	40.16	40.1	42.54	43.14	41.71	42.94	43.45	42.83	40.49	40.62	42.69	43.24	42.83
51	34.08	36.1	39.27	40.93	40.33	40.65	41.82	42.82	43.67	43.49	42.53	38.67	39.85	41.89	41.96	39.24
49	32.35	33.03	35.99	37.02	39.05	41.84	41.74	42.58	41.97	41.05	39.96	39.74	39.21	38.97	36.73	37.8
47	30.12	30.54	33.53	35.58	38.81	39.84	41.3	41.1	39.17	39.47	38.44	37.95	36.2	36.93	37.36	36.22
45	27.85	30.56	33.29	36.07	37.95	38.03	39.93	37.52	37.63	37.65	35.83	35.46	34.05	35.14	35.61	34.95
43	28.62	31.93	31.89	34.14	34.98	35	36.36	34.28	34.95	35.56	35.54	32.86	31.44	32.09	33.75	32.84
41	32.49	32.51	31.54	34.09	32.46	32.76	33.52	32.97	32.22	33.78	32.62	29.85	29.89	29.62	29.65	29.6
39	31.56	31.1	31.01	30.65	30.16	29.81	29.53	30.36	30.67	28.81	27.88	25.4	27.57	26.77	25.59	26.67
37	29.51	29.05	29.71	29.42	28.55	26.99	26.91	29.53	28.2	26.36	23.93	23.14	21.8	23.48	23.14	24.12

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, W2P for Tm, 4 x 4 grid, 50 year return period

LATITUDE (N) \ Longitude W	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	34.61	36.35	38.22	39.42	40.24	41.12	41.16	41.8	42.04	41.8	41.69	42.62	41.68	40.7	41.01	41.18
55	34.69	36.87	37.45	38.41	38.51	39.96	41.07	41.42	40.53	41.46	41.03	41.43	40.06	40.48	41.6	41.26
53	34.13	35.98	37.35	37.22	37.97	39.16	39.93	41.02	41.31	40.32	40.35	39.84	39.97	39.99	40.51	40.95
51	33.38	34	35.99	37.62	38.22	39.24	40.04	39.92	40.95	40.84	39.95	38.18	37.97	38.55	39.24	39.41
49	30.2	32.58	34.2	36.44	37.79	38.42	39.74	40.27	39.68	39.46	38.62	36.78	37.04	37.09	37.09	35.93
47	28.73	30.38	32.07	34.65	36.23	37.45	38.62	37.98	38.26	37.35	36.35	35.4	34.81	35.06	34.96	35.28
45	27.97	28.72	30.46	33.3	34.73	36.07	36.15	36.54	35.39	35.78	34.94	33.27	32.94	33.02	33.11	33.07
43	28.83	29.37	31.3	32.89	33.31	34.19	34.48	33.71	33.71	33.78	33	31.18	30.36	30.9	30.83	30.67
41	30.71	30.29	30.84	30.79	31.27	31.22	31.28	31.17	31.07	30.85	30.2	28.84	28.22	28.49	27.97	27.88
39	30.4	29.87	29.5	29.1	29.05	28.6	29.16	28.85	28.59	28.05	25.67	24.94	25.29	25.7	25.43	24.69
37	28.04	28.64	28.04	27.42	26.53	26.55	26.88	27.17	27.24	25.49	23.2	21.84	21.64	22.52	22.41	22.82

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, W2P for Tm, 4 x 4 grid, 100 year return period

LATITUDE (N) \ Longitude W	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	36.34	38.15	40.1	41.39	42.25	43.16	43.2	43.87	44.14	43.89	43.76	44.74	43.75	42.72	43.05	43.22
55	36.42	38.71	39.29	40.32	40.41	41.94	43.12	43.49	42.54	43.52	43.07	43.49	42.04	42.49	43.66	43.32
53	35.82	37.76	39.2	39.06	39.83	41.09	41.89	43.05	43.37	42.32	42.34	41.81	41.96	41.98	42.54	42.99
51	35.04	35.68	37.76	39.47	40.11	41.17	42.02	41.88	42.98	42.87	41.93	40.07	39.85	40.46	41.2	41.37
49	31.71	34.18	35.88	38.23	39.65	40.32	41.7	42.25	41.64	41.41	40.52	38.59	38.86	38.92	38.94	37.72
47	30.15	31.87	33.64	36.35	38.01	39.3	40.52	39.85	40.15	39.18	38.15	37.14	36.51	36.78	36.68	37.04
45	29.34	30.12	31.93	34.94	36.45	37.84	37.94	38.34	37.12	37.54	36.67	34.9	34.56	34.65	34.76	34.7
43	30.25	30.83	32.83	34.51	34.96	35.88	36.18	35.39	35.37	35.45	34.63	32.71	31.85	32.42	32.36	32.17
41	32.24	31.78	32.37	32.3	32.81	32.76	32.81	32.7	32.6	32.38	31.69	30.26	29.6	29.88	29.36	29.24
39	31.93	31.34	30.96	30.52	30.47	30.01	30.58	30.27	29.99	29.44	26.94	26.17	26.53	26.95	26.67	25.89
37	29.44	30.06	29.44	28.76	27.82	27.85	28.22	28.51	28.6	26.76	24.33	22.9	22.68	23.63	23.49	23.92

Table B-5: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, W2P for mean wave period and the Ochi spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, W2P for Tm, 2 x 2 grid, 50 year return period

LATITUDE (N)	Longitude W: 49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	35.26	35.74	39.31	40.04	40.46	39.81	42.21	42.28	39.96	39.46	42.29	43.46	39.81	38.91	40.02	41.41
55	36.55	36.51	37.89	37.74	36.93	38.47	40.7	41.34	41.57	37.76	40.08	41.24	39.42	39.25	40.45	42.42
53	34	35.46	35.84	37.67	37.61	40.02	40.44	39.03	40.09	40.43	39.84	37.55	37.76	39.75	40.18	39.83
51	32.09	34.12	37.08	38.62	38.05	38.18	39.1	40.07	40.85	40.62	39.67	35.84	36.89	38.85	39	36.13
49	30.27	30.95	33.82	34.64	36.64	39.3	39	39.8	39.22	38.2	37.12	36.83	36.28	36.04	33.89	34.84
47	28.1	28.52	31.4	33.24	36.4	37.34	38.57	38.36	36.5	36.66	35.64	35.08	33.37	34.09	34.48	33.32
45	25.9	28.53	31.22	33.83	35.67	35.62	37.39	35.04	35.09	34.93	33.19	32.76	31.33	32.38	32.8	32.15
43	26.59	29.82	29.89	31.92	32.75	32.63	33.84	31.82	32.52	32.94	32.92	30.31	28.91	29.54	31.02	30.14
41	30.39	30.41	29.53	31.85	30.27	30.44	31.06	30.56	29.86	31.2	30.07	27.39	27.45	27.19	27.07	27.04
39	29.39	28.92	28.82	28.46	27.97	27.53	27.13	27.94	28.24	26.42	25.52	23.12	25.2	24.44	23.2	24.17
37	27.37	26.92	27.58	27.23	26.4	24.85	24.68	27.18	25.98	24.15	21.81	20.97	19.71	21.31	20.89	21.72

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, W2P for Tm, 2 x 2 grid, 100 year return period

LATITUDE (N)	Longitude W: 49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	37.06	37.54	41.3	42.06	42.5	41.81	44.35	44.43	41.97	41.43	44.44	45.66	41.82	40.84	42.02	43.5
55	38.4	38.36	39.79	39.64	38.79	40.4	42.75	43.43	43.67	39.65	42.09	43.33	41.39	41.22	42.49	44.58
53	35.69	37.26	37.62	39.54	39.49	42.03	42.47	40.98	42.1	42.46	41.83	39.42	39.64	41.76	42.21	41.86
51	33.73	35.83	38.97	40.58	39.95	40.08	41.05	42.08	42.9	42.65	41.66	37.62	38.72	40.81	40.97	37.92
49	31.8	32.5	35.51	36.38	38.47	41.28	40.94	41.8	41.19	40.09	38.98	38.66	38.09	37.85	35.57	36.59
47	29.5	29.93	32.96	34.89	38.22	39.21	40.49	40.29	38.32	38.48	37.42	36.83	35.04	35.77	36.22	35
45	27.18	29.96	32.77	35.52	37.47	37.41	39.29	36.81	36.85	36.69	34.83	34.38	32.89	33.99	34.44	33.76
43	27.93	31.33	31.36	33.51	34.38	34.27	35.53	33.41	34.15	34.59	34.57	31.81	30.36	31.02	32.57	31.64
41	31.91	31.93	31	33.45	31.78	31.97	32.63	32.07	31.36	32.78	31.59	28.76	28.8	28.52	28.43	28.38
39	30.84	30.37	30.28	29.87	29.37	28.92	28.49	29.33	29.66	27.74	26.81	24.27	26.44	25.64	24.34	25.35
37	28.73	28.26	28.97	28.61	27.72	26.07	25.91	28.56	27.28	25.35	22.9	22.01	20.68	22.35	21.91	22.78

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, W2P for Tm, 4 x 4 grid, 50 year return period

LATITUDE (N)	Longitude W: 49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	34.27	36.09	37.87	38.85	39.7	40.6	40.53	41.19	41.21	40.72	40.61	41.52	40.59	39.59	39.94	40.29
55	34.3	36.57	37.03	37.8	37.91	39.41	40.4	40.76	39.7	40.5	40.06	40.46	39.14	39.56	40.6	40.32
53	33.71	35.64	36.94	36.58	37.35	38.58	39.22	40.34	40.5	39.33	39.37	38.83	39.04	39.06	39.49	40
51	33.05	33.7	35.61	37.19	37.82	38.69	39.28	39.15	40.17	40	39.09	37.19	36.88	37.47	38.26	38.16
49	29.63	32.09	33.71	35.83	37.23	37.81	38.96	39.5	38.91	38.53	37.68	35.7	35.95	36	36.01	34.77
47	28.12	29.82	31.51	33.99	35.62	36.81	37.8	37.15	37.45	36.38	35.36	34.3	33.69	33.94	33.83	34.11
45	27.34	28.12	29.9	32.72	34.19	35.46	35.46	35.85	34.6	34.84	33.99	32.21	31.83	31.9	31.97	31.92
43	28.18	28.75	30.8	32.28	32.71	33.49	33.67	32.89	32.93	32.83	32.03	30.16	29.32	29.87	29.68	29.5
41	30.12	29.69	30.32	30.12	30.6	30.44	30.39	30.28	30.23	29.85	29.19	27.79	27.15	27.43	26.8	26.7
39	29.71	29.16	28.78	28.34	28.29	27.74	28.16	27.85	27.6	27.03	24.63	23.85	24.2	24.62	24.23	23.43
37	27.28	27.89	27.3	26.62	25.71	25.66	25.93	26.22	26.35	24.51	22.21	20.75	20.55	21.44	21.22	21.54

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, W2P for Tm, 4 x 4 grid, 100 year return period

LATITUDE (N)	Longitude W: 49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	36.01	37.9	39.77	40.81	41.7	42.65	42.56	43.26	43.29	42.77	42.64	43.61	42.63	41.58	41.95	42.32
55	36.04	38.42	38.89	39.71	39.81	41.4	42.45	42.82	41.69	42.54	42.07	42.5	41.09	41.55	42.64	42.36
53	35.41	37.43	38.8	38.41	39.2	40.51	41.17	42.37	42.55	41.31	41.33	40.77	41.02	41.03	41.49	42.03
51	34.72	35.39	37.39	39.06	39.72	40.63	41.25	41.1	42.19	42.02	41.05	39.04	38.72	39.35	40.19	40.08
49	31.14	33.69	35.4	37.62	39.09	39.7	40.91	41.47	40.86	40.47	39.56	37.48	37.74	37.8	37.82	36.52
47	29.53	31.31	33.07	35.68	37.39	38.64	39.69	39	39.32	38.18	37.13	36.01	35.35	35.62	35.52	35.82
45	28.7	29.51	31.37	34.35	35.92	37.23	37.24	37.65	36.32	36.58	35.69	33.81	33.4	33.49	33.58	33.51
43	29.59	30.2	32.33	33.89	34.36	35.16	35.35	34.55	34.58	34.48	33.64	31.66	30.78	31.35	31.16	30.96
41	31.65	31.18	31.86	31.61	32.14	31.97	31.91	31.79	31.75	31.36	30.66	29.18	28.51	28.78	28.14	28.02
39	31.22	30.62	30.22	29.74	29.69	29.13	29.55	29.24	28.98	28.38	25.86	25.03	25.4	25.82	25.42	24.58
37	28.65	29.29	28.69	27.94	26.98	26.94	27.23	27.53	27.68	25.75	23.3	21.78	21.56	22.5	22.25	22.58

Table B-6: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, Average (FT1 & W2P) and the Bretschneider spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, Average for Tm, 2 x 2 grid, 50 year return period

		Longitude															
		W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	35.06	35.51	39.01	39.96	40.35	39.75	42.14	42.21	40.2	39.94	42.66	43.82	40.27	39.4	40.44	41.63
	55	36.32	36.28	37.71	37.79	37.02	38.47	40.73	41.34	41.7	38.17	40.4	41.54	39.72	39.56	40.81	42.63
	53	33.9	35.29	35.76	37.72	37.66	39.94	40.48	39.14	40.28	40.74	40.17	37.99	38.13	40.04	40.55	40.15
	51	32.01	33.93	36.88	38.43	37.89	38.17	39.25	40.18	40.97	40.83	39.91	36.29	37.39	39.28	39.35	36.8
	49	30.38	31.03	33.8	34.77	36.67	39.26	39.17	39.94	39.38	38.53	37.49	37.28	36.79	36.56	34.47	35.43
	47	28.3	28.7	31.5	33.42	36.44	37.4	38.76	38.56	36.77	37.05	36.06	35.59	33.98	34.67	35.04	33.95
	45	26.18	28.71	31.28	33.88	35.62	35.7	37.45	35.21	35.33	35.32	33.64	33.29	31.95	32.97	33.4	32.78
	43	26.87	29.97	29.98	32.07	32.86	32.86	34.11	32.17	32.81	33.36	33.34	30.86	29.5	30.11	31.66	30.81
	41	30.51	30.53	29.64	32	30.49	30.76	31.44	30.95	30.25	31.68	30.59	28.01	28.07	27.82	27.8	27.78
	39	29.65	29.2	29.1	28.79	28.32	27.96	27.7	28.49	28.79	27.04	26.17	23.84	25.89	25.14	24.03	25.03
	37	27.71	27.28	27.89	27.6	26.8	25.36	25.25	27.69	26.48	24.76	22.46	21.72	20.47	22.06	21.74	22.64

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, Average for Tm, 2 x 2 grid, 100 year return period

		Longitude															
		W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	36.77	37.23	40.91	41.9	42.31	41.68	44.2	44.27	42.15	41.86	44.75	45.96	42.23	41.29	42.4	43.65
	55	38.08	38.05	39.52	39.61	38.81	40.33	42.71	43.35	43.73	40.01	42.36	43.57	41.63	41.47	42.79	44.71
	53	35.52	37	37.47	39.52	39.47	41.87	42.44	41.03	42.23	42.71	42.11	39.82	39.96	41.99	42.52	42.11
	51	33.58	35.56	38.68	40.29	39.7	40	41.13	42.12	42.96	42.8	41.85	38.03	39.18	41.18	41.26	38.56
	49	31.85	32.51	35.43	36.44	38.43	41.17	41.05	41.87	41.29	40.37	39.3	39.07	38.57	38.33	36.12	37.15
	47	29.65	30.07	33	35.02	38.2	39.2	40.62	40.43	38.53	38.82	37.81	37.31	35.61	36.32	36.75	35.6
	45	27.43	30.1	32.77	35.5	37.35	37.42	39.28	36.91	37.03	37.03	35.24	34.87	33.48	34.55	35.01	34.36
	43	28.16	31.42	31.4	33.61	34.44	34.44	35.75	33.72	34.4	34.97	34.95	32.33	30.92	31.57	33.19	32.3
	41	31.98	32	31.06	33.56	31.96	32.24	32.96	32.43	31.71	33.22	32.08	29.36	29.41	29.14	29.15	29.11
	39	31.06	30.61	30.51	30.17	29.68	29.32	29.04	29.86	30.18	28.35	27.44	24.99	27.12	26.34	25.17	26.21
	37	29.04	28.59	29.23	28.95	28.09	26.56	26.47	29.05	27.76	25.94	23.55	22.76	21.44	23.1	22.76	23.7

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, Average for Tm, 4 x 4 grid, 50 year return period

		Longitude															
		W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	34.12	35.83	37.65	38.83	39.64	40.51	40.55	41.17	41.4	41.15	41.04	41.95	41.02	40.06	40.37	40.56
	55	34.19	36.33	36.9	37.84	37.95	39.37	40.45	40.79	39.91	40.81	40.38	40.79	39.45	39.86	40.96	40.62
	53	33.63	35.45	36.81	36.68	37.41	38.58	39.32	40.39	40.68	39.68	39.72	39.22	39.36	39.38	39.89	40.31
	51	32.92	33.53	35.49	37.08	37.67	38.66	39.43	39.31	40.33	40.24	39.36	37.59	37.37	37.94	38.64	38.77
	49	29.76	32.11	33.7	35.9	37.23	37.85	39.13	39.65	39.08	38.85	38.03	36.19	36.47	36.53	36.52	35.36
	47	28.32	29.94	31.6	34.14	35.7	36.89	38.02	37.4	37.68	36.78	35.8	34.84	34.28	34.53	34.42	34.72
	45	27.57	28.31	30.02	32.81	34.22	35.54	35.61	35.98	34.86	35.23	34.41	32.75	32.43	32.5	32.59	32.55
	43	28.4	28.94	30.85	32.41	32.83	33.68	33.95	33.19	33.21	33.26	32.49	30.71	29.9	30.43	30.35	30.19
	41	30.26	29.84	30.39	30.34	30.81	30.76	30.79	30.68	30.6	30.38	29.73	28.41	27.79	28.06	27.54	27.44
	39	29.95	29.43	29.06	28.68	28.62	28.16	28.71	28.4	28.16	27.64	25.29	24.56	24.91	25.32	25.04	24.3
	37	27.62	28.22	27.62	27.01	26.13	26.15	26.47	26.76	26.84	25.12	22.86	21.5	21.31	22.18	22.06	22.46

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Bretschneider spectrum, Average for Tm, 4 x 4 grid, 100 year return period

		Longitude															
		W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	35.78	37.57	39.47	40.72	41.56	42.47	42.5	43.16	43.41	43.15	43.03	43.99	43.01	42	42.33	42.52
	55	35.85	38.1	38.68	39.68	39.77	41.28	42.42	42.78	41.84	42.79	42.34	42.77	41.35	41.79	42.93	42.6
	53	35.25	37.16	38.59	38.45	39.2	40.44	41.2	42.35	42.66	41.61	41.63	41.12	41.28	41.29	41.83	42.27
	51	34.52	35.15	37.18	38.86	39.49	40.52	41.33	41.19	42.28	42.19	41.26	39.4	39.18	39.78	40.52	40.65
	49	31.22	33.65	35.32	37.62	39.02	39.67	41.02	41.55	40.96	40.73	39.86	37.93	38.23	38.28	38.29	37.08
	47	29.69	31.38	33.11	35.77	37.41	38.67	39.85	39.19	39.5	38.54	37.52	36.51	35.91	36.18	36.07	36.4
	45	28.89	29.66	31.44	34.39	35.88	37.24	37.33	37.72	36.53	36.92	36.06	34.32	33.98	34.07	34.18	34.11
	43	29.77	30.34	32.32	33.97	34.42	35.3	35.58	34.81	34.81	34.86	34.06	32.18	31.34	31.89	31.82	31.64
	41	31.73	31.28	31.87	31.79	32.3	32.24	32.27	32.16	32.08	31.85	31.17	29.77	29.12	29.39	28.86	28.76
	39	31.42	30.84	30.46	30.04	29.99	29.52	30.07	29.77	29.51	28.97	26.51	25.74	26.11	26.52	26.24	25.45
	37	28.97	29.58	28.96	28.3	27.37	27.4	27.76	28.05	28.15	26.34	23.94	22.53	22.32	23.24	23.09	23.51

Table B-7: Most probable extreme wave heights predicted using FT1/IDM for significant wave height, Average (FT1 & W2P) for wave period and the Ochi spectrum for short term order statistics

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, Average for Tm, 2 x 2 grid, 50 year return period

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	33.8	34.25	37.63	38.31	38.71	38.12	40.4	40.47	38.25	37.77	40.46	41.59	38.09	37.23	38.3	39.67
	55	35	34.96	36.28	36.17	35.4	36.85	38.95	39.56	39.79	36.12	38.33	39.47	37.74	37.58	38.72	40.58
	53	32.56	33.96	34.32	36.1	36.04	38.33	38.7	37.35	38.38	38.67	38.1	35.95	36.16	38.06	38.46	38.12
	51	30.81	32.74	35.56	37	36.46	36.57	37.41	38.34	39.1	38.93	38.02	34.31	35.31	37.17	37.33	34.57
	49	29.03	29.68	32.4	33.2	35.11	37.62	37.31	38.08	37.56	36.57	35.54	35.22	34.76	34.53	32.47	33.33
	47	26.95	27.35	30.09	31.85	34.87	35.75	36.9	36.71	34.95	35.1	34.13	33.55	31.99	32.67	33.03	31.88
	45	24.86	27.38	29.93	32.41	34.17	34.12	35.79	33.55	33.63	33.45	31.79	31.37	30.01	31.01	31.4	30.78
	43	25.49	28.57	28.66	30.6	31.4	31.26	32.38	30.46	31.17	31.54	31.52	29.06	27.72	28.32	29.71	28.88
	41	29.11	29.13	28.32	30.53	29.02	29.17	29.73	29.26	28.63	29.88	28.81	26.27	26.32	26.08	25.95	25.92
	39	28.17	27.72	27.61	27.29	26.83	26.37	25.99	26.76	27.09	25.35	24.49	22.18	24.19	23.46	22.27	23.16
	37	26.23	25.81	26.43	26.1	25.3	23.83	23.66	26.05	24.93	23.18	20.95	20.13	18.93	20.46	20.05	20.83

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, Average for Tm, 2 x 2 grid, 100 year return period

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	35.41	35.87	39.41	40.12	40.53	39.91	42.32	42.39	40.04	39.52	42.38	43.56	39.89	38.96	40.09	41.54
	55	36.65	36.62	37.98	37.87	37.06	38.58	40.78	41.42	41.67	37.81	40.13	41.34	39.51	39.35	40.54	42.51
	53	34.08	35.56	35.92	37.78	37.72	40.13	40.51	39.1	40.18	40.49	39.89	37.63	37.85	39.86	40.28	39.93
	51	32.28	34.28	37.26	38.76	38.16	38.27	39.16	40.13	40.95	40.75	39.81	35.91	36.94	38.92	39.09	36.17
	49	30.4	31.06	33.92	34.75	36.74	39.4	39.05	39.87	39.32	38.27	37.21	36.86	36.39	36.16	33.98	34.89
	47	28.21	28.62	31.49	33.34	36.51	37.43	38.63	38.43	36.58	36.73	35.73	35.12	33.48	34.18	34.59	33.38
	45	26.02	28.67	31.32	33.93	35.78	35.73	37.48	35.12	35.2	35.02	33.26	32.82	31.41	32.46	32.88	32.23
	43	26.69	29.92	29.98	32.03	32.86	32.72	33.9	31.88	32.64	33.01	33	30.41	29.02	29.65	31.1	30.23
	41	30.48	30.49	29.64	31.98	30.39	30.54	31.14	30.61	29.98	31.29	30.17	27.51	27.54	27.27	27.17	27.13
	39	29.47	29.03	28.92	28.56	28.08	27.62	27.21	28.01	28.37	26.54	25.65	23.22	25.31	24.55	23.29	24.23
	37	27.45	27.01	27.66	27.34	26.49	24.93	24.77	27.29	26.1	24.26	21.93	21.07	19.8	21.4	20.96	21.78

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, Average for Tm, 4 x 4 grid, 50 year return period

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	32.85	34.58	36.26	37.17	37.98	38.88	38.8	39.43	39.44	38.96	38.86	39.74	38.83	37.88	38.23	38.6
	55	32.85	35.01	35.47	36.22	36.33	37.75	38.66	39	38	38.74	38.31	38.73	37.47	37.88	38.87	38.58
	53	32.29	34.12	35.37	35.05	35.79	36.96	37.53	38.61	38.77	37.62	37.66	37.17	37.39	37.4	37.81	38.28
	51	31.72	32.34	34.16	35.64	36.24	37.06	37.59	37.47	38.46	38.34	37.47	35.6	35.29	35.85	36.63	36.5
	49	28.41	30.76	32.29	34.33	35.66	36.2	37.28	37.79	37.25	36.89	36.07	34.15	34.45	34.5	34.49	33.26
	47	26.97	28.59	30.2	32.57	34.13	35.25	36.17	35.55	35.86	34.83	33.86	32.81	32.28	32.53	32.42	32.63
	45	26.25	26.98	28.67	31.35	32.76	33.96	33.94	34.32	33.16	33.36	32.55	30.85	30.49	30.56	30.61	30.56
	43	27.01	27.55	29.53	30.95	31.36	32.08	32.22	31.47	31.56	31.43	30.67	28.92	28.11	28.63	28.43	28.27
	41	28.86	28.45	29.07	28.88	29.35	29.17	29.1	28.99	28.98	28.6	27.96	26.66	26.04	26.3	25.69	25.59
	39	28.47	27.95	27.58	27.18	27.13	26.57	26.97	26.67	26.48	25.93	23.64	22.87	23.23	23.63	23.25	22.46
	37	26.15	26.73	26.16	25.52	24.65	24.61	24.85	25.13	25.29	23.53	21.33	19.92	19.74	20.58	20.36	20.66

Extreme H (in meters) prediction using the Ochi short term extremal statistics and the Ochi spectrum, Average for Tm, 4 x 4 grid, 100 year return period

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	34.41	36.21	37.96	38.93	39.78	40.7	40.62	41.28	41.3	40.8	40.68	41.61	40.66	39.66	40.02	40.42
	55	34.4	36.67	37.13	37.94	38.03	39.53	40.49	40.85	39.79	40.56	40.12	40.55	39.22	39.67	40.69	40.41
	53	33.81	35.73	37.04	36.7	37.45	38.69	39.28	40.42	40.61	39.39	39.41	38.91	39.15	39.17	39.59	40.09
	51	33.23	33.86	35.75	37.31	37.95	38.79	39.35	39.21	40.27	40.15	39.22	37.26	36.94	37.54	38.35	38.22
	49	29.77	32.2	33.81	35.93	37.33	37.9	39.02	39.55	39	38.62	37.75	35.74	36.05	36.11	36.11	34.82
	47	28.24	29.93	31.6	34.09	35.72	36.89	37.86	37.21	37.54	36.45	35.45	34.34	33.78	34.04	33.92	34.16
	45	27.47	28.24	29.99	32.81	34.3	35.55	35.53	35.93	34.7	34.92	34.07	32.28	31.9	31.99	32.06	31.98
	43	28.27	28.85	30.9	32.39	32.84	33.58	33.72	32.96	33.04	32.91	32.12	30.27	29.42	29.96	29.77	29.59
	41	30.23	29.78	30.45	30.22	30.72	30.54	30.45	30.34	30.35	29.94	29.28	27.91	27.26	27.52	26.89	26.78
	39	29.83	29.26	28.86	28.44	28.39	27.81	28.22	27.92	27.72	27.15	24.75	23.94	24.32	24.72	24.32	23.49
	37	27.38	27.98	27.4	26.7	25.78	25.75	26.02	26.3	26.49	24.65	22.31	20.85	20.64	21.54	21.28	21.59

Table B-8: Most probable extreme wave amplitudes (RMS) predicted using the Alves and Young's extreme Hs data and a wave simulation (3 hrs) using the Pierson-Moskowitz spectrum

Extreme wave amplitude (in meters) using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 50 year return period, 3 hr duration

LATITUDE (N)	Longitude W: 49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	17.70	18.89	20.82	20.93	21.36	21.34	22.75	21.34	21.31	21.54	23.32	21.39	21.01	22.69	20.57	21.68
55	19.71	18.53	20.08	21.18	19.61	20.94	21.71	21.13	21.94	20.88	20.76	22.52	20.75	20.64	21.85	22.40
53	18.04	19.79	18.13	19.39	20.25	22.82	20.40	20.00	20.87	21.06	21.52	19.79	20.29	21.84	22.59	21.73
51	16.96	17.40	18.86	20.46	20.78	20.16	20.14	20.78	22.79	21.27	20.41	19.39	21.55	20.88	21.79	19.50
49	15.88	15.93	17.82	17.81	19.33	22.22	20.19	21.54	20.59	19.57	19.46	18.94	19.05	19.76	17.63	20.93
47	15.73	14.94	16.75	17.55	19.13	19.81	20.82	20.08	19.93	20.53	20.01	19.12	17.72	18.74	17.08	18.64
45	13.87	14.89	17.16	17.57	19.56	18.98	19.82	19.90	17.85	18.63	18.84	17.34	17.50	18.51	18.22	17.97
43	14.39	15.84	15.98	16.91	18.14	16.62	18.45	17.52	18.33	17.66	16.99	16.10	15.11	16.15	17.52	17.22
41	16.74	15.94	15.25	17.25	16.15	16.72	16.36	15.64	15.33	16.10	16.23	15.17	15.25	14.28	14.59	15.09
39	15.32	15.78	15.22	15.70	15.43	15.01	15.26	15.13	15.12	14.52	14.22	12.16	12.80	13.44	12.86	12.88
37	14.87	14.05	13.80	14.20	14.09	12.90	13.23	14.81	13.66	12.87	11.71	11.23	11.37	11.65	11.57	11.61

Extreme wave amplitude (in meters) using wave simulation based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 100 year return period, 3 hr duration

LATITUDE (N)	Longitude W: 49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	20.69	19.74	21.97	21.11	23.59	21.47	22.80	24.75	21.61	22.64	23.85	24.34	21.46	21.89	22.54	23.63
55	19.93	21.00	20.84	20.76	19.96	21.00	22.28	24.49	23.15	21.97	22.05	23.96	21.34	21.24	23.40	24.61
53	18.16	18.76	18.55	20.94	21.02	23.34	23.77	22.71	22.30	22.18	22.76	22.11	21.64	22.60	22.32	23.42
51	18.09	18.65	21.46	21.50	20.60	20.76	21.73	22.48	22.98	22.05	22.45	20.80	20.72	21.02	21.56	19.59
49	17.22	17.28	17.65	19.05	21.13	21.11	23.80	22.04	20.89	21.75	21.17	20.32	19.93	20.83	18.78	19.21
47	15.94	14.50	17.06	18.82	20.06	20.20	22.87	21.59	22.56	20.38	20.10	18.69	20.47	18.71	19.71	19.31
45	14.64	16.26	17.69	19.89	19.50	20.14	22.46	20.30	19.76	19.16	18.96	18.80	17.11	17.80	18.54	17.32
43	15.58	16.07	16.82	16.98	17.83	18.33	17.96	17.21	18.92	18.88	19.48	17.12	15.95	15.98	17.66	17.16
41	17.11	16.48	17.31	17.57	17.78	16.11	18.74	17.20	16.44	18.43	17.56	15.64	16.49	15.76	15.28	15.90
39	15.69	15.51	15.70	14.63	15.45	15.52	16.48	16.23	16.96	15.41	14.76	13.64	14.12	14.36	13.35	13.82
37	14.85	15.23	14.82	15.22	14.53	14.56	13.99	15.38	14.41	14.07	12.69	12.29	11.44	12.21	12.82	12.79

Table B-9: Most probable extreme wave amplitudes (RMS) predicted using the Alves and Young's extreme Hs data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Extreme wave amplitude (in meters) using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 50 year return period, 3 day duration

LATITUDE (N)	Longitude W 49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	21.44	21.44	23.31	24.06	24.75	24.28	25.36	25.85	24.58	23.93	26.67	26.57	24.86	24.73	25.32	25.13
55	22.07	22.27	23.14	22.82	22.95	23.31	25.00	24.94	24.98	23.62	24.70	25.49	25.59	24.76	24.96	25.68
53	20.11	21.56	21.88	23.06	22.73	23.72	25.08	23.68	25.00	25.46	25.24	23.17	23.57	24.32	25.13	24.64
51	19.50	20.68	22.60	23.09	22.73	23.54	24.21	24.54	25.26	24.86	24.75	21.92	22.93	24.29	24.30	22.45
49	18.64	18.97	20.17	21.40	22.71	23.70	23.51	24.22	23.90	23.44	23.08	23.00	23.13	22.38	21.03	21.77
47	17.42	17.37	18.91	20.59	22.08	22.95	23.80	23.61	22.78	22.78	21.81	21.83	21.05	21.43	21.28	21.04
45	16.11	17.49	19.32	20.50	21.87	21.97	22.85	21.20	21.89	21.73	20.45	20.49	19.50	20.32	20.95	20.04
43	16.11	17.90	18.43	19.62	20.10	20.01	20.78	19.31	20.77	20.51	20.35	18.90	18.13	18.52	19.35	19.08
41	18.42	18.53	17.94	19.72	18.76	18.53	19.00	18.93	18.31	19.41	18.45	16.97	17.23	16.78	16.88	16.85
39	18.24	17.91	17.79	17.44	16.93	16.96	16.89	17.24	17.75	16.52	16.10	14.68	15.65	15.47	14.95	15.54
37	16.61	16.44	17.00	16.64	16.21	15.42	15.36	16.73	15.99	15.26	13.93	13.09	12.40	13.56	13.20	13.78

Extreme wave amplitude (in meters) using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 100 year return period, 3 day duration

LATITUDE (N)	Longitude W 49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
57	22.49	22.54	24.79	25.26	25.98	25.10	27.38	27.20	26.03	25.99	27.79	28.11	26.50	25.63	26.06	27.22
55	22.76	22.87	24.23	24.00	23.86	24.76	26.46	26.59	26.69	24.20	25.78	26.55	26.01	24.84	26.10	27.20
53	21.36	22.74	23.08	24.22	23.70	25.90	25.97	24.23	26.37	26.09	26.08	24.78	24.55	25.24	25.97	25.32
51	20.08	21.77	24.04	24.70	24.01	24.52	25.46	25.90	25.88	26.44	25.77	23.37	24.22	25.57	25.60	24.28
49	19.20	20.01	21.51	22.27	23.51	25.34	25.56	25.78	25.57	25.18	23.92	23.95	24.14	23.34	22.09	22.64
47	18.00	18.47	20.02	21.73	23.30	24.12	24.83	24.57	23.91	23.76	23.35	22.95	21.81	22.53	22.45	21.64
45	16.72	18.47	19.69	22.00	22.59	22.56	24.34	22.63	22.69	22.52	21.67	21.21	20.35	21.17	21.73	21.54
43	17.43	18.98	18.98	20.25	20.82	20.89	21.87	21.16	20.55	21.62	21.27	19.92	18.77	19.17	20.49	20.06
41	19.70	19.34	18.80	20.55	19.63	19.86	19.73	19.96	19.35	20.45	19.38	18.04	17.61	18.03	17.73	17.89
39	18.86	18.59	18.63	18.38	18.15	17.93	17.94	18.40	18.17	17.30	16.69	15.43	16.45	16.16	15.63	16.27
37	17.36	17.43	17.66	17.70	17.48	16.09	16.08	17.86	16.85	15.78	14.11	14.05	13.04	14.03	13.76	14.54

Table B-10: Most probable extreme wave heights predicted using the Alves and Young's extreme Hs data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Extreme wave height (in meters) using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 50 year return period, 3 day duration

		Longitude W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	37.24	37.46	41.09	42.07	43.52	42.15	44.74	45.06	43.30	42.46	46.29	46.53	43.67	43.03	43.71	43.89
	55	38.39	40.73	40.04	39.95	39.99	40.39	43.41	43.90	43.89	41.08	43.27	44.39	44.09	43.31	43.19	44.68
	53	35.09	37.33	38.49	40.00	39.75	41.81	43.30	41.60	44.01	44.42	43.19	40.45	41.10	42.23	43.72	42.75
	51	33.81	36.50	39.69	40.76	39.51	41.12	41.64	43.21	43.59	43.15	43.32	38.49	39.71	41.98	42.00	39.99
	49	32.28	33.26	35.01	37.06	39.37	41.85	40.82	42.63	41.88	41.14	40.06	39.76	40.42	38.57	36.74	38.39
	47	30.39	30.20	32.93	36.20	39.09	40.19	41.25	41.25	39.37	39.25	37.67	38.18	36.86	37.02	37.29	36.52
	45	27.87	30.27	33.24	35.56	37.43	37.66	39.80	36.89	37.97	38.48	35.64	35.28	34.09	35.77	35.93	35.26
	43	28.67	31.58	31.74	33.90	35.20	34.98	36.19	33.75	35.69	35.92	35.21	32.97	31.40	32.11	33.61	33.55
	41	32.48	32.21	31.12	34.11	32.70	32.13	33.09	33.05	32.00	33.67	32.29	29.39	29.79	29.31	29.58	29.01
	39	31.26	30.84	31.23	30.45	29.99	29.86	29.56	30.24	31.13	28.81	28.11	25.57	27.15	26.63	25.60	27.21
	37	28.94	29.04	29.31	29.17	28.56	26.69	26.75	29.23	28.16	26.15	24.19	22.81	21.34	23.53	23.12	23.96

Extreme wave height (in meters) using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 100 year return period, 3 day duration

		Longitude W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	38.79	39.16	43.33	44.20	45.54	44.40	47.07	47.37	45.42	45.45	48.16	49.65	45.76	44.25	45.31	47.15
	55	39.90	40.05	42.03	41.94	41.33	43.29	46.31	46.79	46.89	42.21	45.18	46.78	45.54	44.12	45.44	47.57
	53	37.05	39.37	40.12	42.45	41.77	44.38	45.30	43.23	45.39	45.82	45.24	43.33	42.97	44.08	45.23	44.62
	51	35.29	37.81	41.50	43.11	41.95	43.82	44.23	45.77	45.63	46.59	44.99	40.99	42.18	44.53	44.29	41.82
	49	33.71	34.64	37.38	38.67	41.08	44.30	45.00	44.32	44.62	44.14	41.61	42.44	42.43	40.96	38.66	39.30
	47	31.41	32.09	34.89	37.42	40.65	41.67	43.48	43.22	41.32	41.56	40.54	39.39	38.19	38.95	38.45	37.66
	45	29.20	32.27	34.24	37.93	39.73	39.45	41.79	38.99	39.78	39.32	37.12	37.02	35.62	36.93	38.33	37.91
	43	30.48	32.55	33.27	34.66	36.49	36.56	38.25	36.42	35.69	37.85	37.17	34.64	33.04	33.13	36.14	34.78
	41	34.38	33.99	32.92	35.20	34.12	34.22	34.65	34.63	33.68	35.48	33.99	31.20	31.54	31.05	31.04	30.90
	39	32.75	32.48	32.43	31.70	31.60	30.98	31.48	32.18	31.59	30.49	29.27	26.49	28.68	27.74	27.00	28.30
	37	30.66	30.94	30.95	30.85	30.12	28.25	28.04	30.88	29.27	27.24	24.45	24.33	22.53	24.71	23.85	25.57

Table B-11: Extreme wave mean zero crossing period predicted using the Alves and Young's extreme Hs data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Mean zero crossing period (in second) using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 50 year return period, 3 day duration

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	16.75	16.83	17.57	17.80	17.89	17.77	18.26	18.27	17.90	17.87	18.42	18.66	17.95	17.77	17.96	18.21
	55	17.00	17.01	17.32	17.36	17.20	17.50	17.99	18.10	18.21	17.49	17.96	18.16	17.80	17.77	18.04	18.39
	53	16.49	16.80	16.92	17.35	17.34	17.82	17.94	17.66	17.90	18.02	17.91	17.46	17.47	17.86	17.98	17.92
	51	16.05	16.47	17.13	17.47	17.37	17.44	17.68	17.88	18.05	18.01	17.84	17.11	17.33	17.73	17.74	17.24
	49	15.69	15.84	16.47	16.71	17.12	17.67	17.69	17.85	17.71	17.56	17.34	17.31	17.21	17.16	16.71	16.92
	47	15.22	15.30	15.96	16.41	17.07	17.28	17.61	17.54	17.17	17.24	17.04	16.96	16.60	16.74	16.82	16.61
	45	14.68	15.29	15.91	16.50	16.88	16.91	17.28	16.81	16.87	16.86	16.50	16.44	16.15	16.37	16.47	16.33
	43	14.86	15.61	15.59	16.11	16.28	16.29	16.59	16.16	16.29	16.44	16.43	15.87	15.56	15.70	16.08	15.87
	41	15.74	15.73	15.52	16.10	15.74	15.81	15.99	15.89	15.71	16.06	15.81	15.19	15.22	15.16	15.16	15.17
	39	15.54	15.42	15.41	15.34	15.23	15.16	15.12	15.30	15.37	14.97	14.74	14.15	14.67	14.50	14.22	14.49
	37	15.09	14.97	15.12	15.06	14.85	14.51	14.50	15.11	14.80	14.38	13.78	13.59	13.25	13.69	13.62	13.87

Mean zero crossing period (in second) using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 100 year return period, 3 day duration

		Longitude W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	17.11	17.22	17.99	18.22	18.31	18.18	18.69	18.71	18.30	18.28	18.85	19.09	18.36	18.17	18.39	18.60
	55	17.39	17.39	17.71	17.76	17.59	17.92	18.38	18.52	18.59	17.90	18.37	18.60	18.20	18.16	18.45	18.83
	53	16.86	17.17	17.29	17.73	17.72	18.22	18.33	18.06	18.31	18.45	18.32	17.86	17.88	18.29	18.41	18.32
	51	16.41	16.84	17.51	17.85	17.74	17.83	18.11	18.28	18.45	18.43	18.24	17.49	17.71	18.14	18.15	17.62
	49	16.05	16.21	16.84	17.08	17.49	18.08	18.07	18.23	18.11	17.94	17.73	17.70	17.58	17.54	17.08	17.32
	47	15.55	15.65	16.31	16.77	17.44	17.68	17.97	17.94	17.56	17.64	17.42	17.32	16.97	17.12	17.21	16.98
	45	15.01	15.65	16.25	16.86	17.26	17.29	17.69	17.19	17.21	17.24	16.86	16.80	16.49	16.73	16.84	16.70
	43	15.18	15.96	15.95	16.45	16.64	16.65	16.95	16.52	16.66	16.79	16.80	16.21	15.90	16.04	16.42	16.23
	41	16.09	16.09	15.86	16.45	16.08	16.17	16.34	16.23	16.07	16.42	16.17	15.52	15.55	15.49	15.51	15.50
	39	15.88	15.79	15.75	15.68	15.57	15.50	15.44	15.64	15.72	15.28	15.08	14.47	15.00	14.81	14.53	14.81
	37	15.42	15.31	15.46	15.40	15.19	14.83	14.82	15.45	15.13	14.68	14.07	13.89	13.53	13.97	13.90	14.17

Table B-12: Mean minimum wave length of extreme wave predicted using the Alves and Young's data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum

Using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 50 year return period, 3 day storm duration

		Longitude W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	225.99	222.99	240.99	243.99	249.99	243.99	249.99	249.99	249.99	246.99	249.99	249.99	249.99	249.99	249.99	249.99
	55	222.99	225.99	243.99	243.99	240.99	243.99	249.99	249.99	253.66	243.99	249.99	249.99	249.99	243.99	249.99	249.99
	53	210.99	222.99	225.99	243.99	240.99	249.99	249.99	246.99	249.99	249.99	249.99	243.99	246.99	249.99	249.99	249.99
	51	175.00	199.00	231.99	246.99	243.99	243.99	249.99	249.99	249.99	253.66	246.99	231.99	243.99	246.99	249.99	240.99
	49	160.00	163.00	208.00	216.99	237.99	249.99	240.99	240.99	249.99	234.99	237.99	234.99	225.99	246.99	222.99	231.99
	47	160.00	166.00	178.00	202.00	243.99	243.99	240.99	243.99	234.99	231.99	237.99	219.99	210.99	210.99	222.99	208.00
	45	160.00	160.00	166.00	205.00	219.99	213.99	246.99	222.99	225.99	225.99	205.00	202.00	181.00	199.00	205.00	196.00
	43	160.00	166.00	160.00	178.00	196.00	187.00	210.99	181.00	181.00	193.00	193.00	166.00	163.00	163.00	166.00	172.00
	41	172.00	166.00	160.00	178.00	160.00	169.00	175.00	166.00	160.00	169.00	169.00	160.00	160.00	160.00	160.00	160.00
	39	160.00	160.00	163.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
	37	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	157.66	153.00	160.00	160.00	160.00

Using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 100 year return period, 3 day storm duration

		Longitude W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	234.99	228.99	249.99	249.99	249.99	249.99	257.33	253.66	249.99	249.99	260.99	271.99	249.99	249.99	249.99	249.99
	55	243.99	240.99	243.99	246.99	243.99	249.99	253.66	260.99	249.99	249.99	249.99	257.33	249.99	249.99	249.99	253.66
	53	228.99	228.99	234.99	240.99	246.99	249.99	249.99	249.99	249.99	249.99	249.99	243.99	249.99	249.99	257.33	249.99
	51	184.00	219.99	246.99	246.99	246.99	246.99	249.99	249.99	249.99	249.99	249.99	243.99	246.99	249.99	249.99	246.99
	49	184.00	190.00	231.99	225.99	240.99	249.99	249.99	249.99	249.99	249.99	249.99	240.99	243.99	249.99	228.99	228.99
	47	160.00	163.00	193.00	219.99	243.99	246.99	249.99	249.99	240.99	243.99	240.99	228.99	234.99	228.99	240.99	225.99
	45	160.00	163.00	175.00	222.99	231.99	237.99	246.99	243.99	243.99	234.99	228.99	222.99	205.00	228.99	210.99	210.99
	43	160.00	169.00	169.00	205.00	213.99	219.99	216.99	210.99	216.99	225.99	222.99	184.00	166.00	181.00	199.00	187.00
	41	184.00	178.00	166.00	210.99	181.00	196.00	190.00	181.00	175.00	196.00	184.00	163.00	160.00	160.00	163.00	160.00
	39	175.00	166.00	160.00	169.00	166.00	163.00	166.00	166.00	166.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
	37	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	153.00	160.00	160.00	160.00

Table B-13: Extreme wave vertical velocity (RMS) predicted using the Alves and Young's data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum (m/s)

Using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 50 year return period, 3 day storm duration

		Longitude															
		W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	1.88	1.90	2.00	2.03	2.04	2.02	2.09	2.09	2.04	2.03	2.11	2.14	2.04	2.02	2.05	2.08
	55	1.92	1.92	1.96	1.97	1.95	1.99	2.05	2.07	2.08	1.98	2.05	2.08	2.03	2.02	2.06	2.10
	53	1.85	1.89	1.91	1.96	1.96	2.03	2.04	2.01	2.04	2.05	2.04	1.98	1.98	2.03	2.05	2.04
	51	1.79	1.85	1.94	1.98	1.97	1.98	2.01	2.04	2.06	2.05	2.03	1.93	1.96	2.02	2.02	1.95
	49	1.74	1.76	1.85	1.88	1.93	2.01	2.01	2.03	2.01	1.99	1.96	1.96	1.95	1.94	1.88	1.91
	47	1.68	1.69	1.78	1.84	1.93	1.96	2.00	1.99	1.94	1.95	1.92	1.91	1.87	1.89	1.90	1.87
	45	1.61	1.69	1.77	1.85	1.90	1.91	1.96	1.89	1.90	1.90	1.85	1.84	1.80	1.84	1.85	1.83
	43	1.63	1.73	1.73	1.80	1.82	1.82	1.86	1.81	1.82	1.84	1.84	1.77	1.73	1.75	1.80	1.77
	41	1.75	1.75	1.72	1.80	1.75	1.76	1.78	1.77	1.75	1.79	1.76	1.68	1.68	1.67	1.67	1.67
	39	1.72	1.71	1.71	1.70	1.68	1.67	1.67	1.69	1.70	1.65	1.62	1.54	1.61	1.58	1.55	1.58
	37	1.66	1.65	1.67	1.66	1.63	1.59	1.58	1.67	1.62	1.57	1.48	1.46	1.41	1.47	1.46	1.50

Using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 100 year return period, 3 day storm duration

		Longitude															
		W															
		49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
LATITUDE (N)	57	1.93	1.95	2.05	2.08	2.09	2.07	2.14	2.14	2.09	2.09	2.16	2.19	2.10	2.07	2.10	2.13
	55	1.97	1.97	2.01	2.02	2.00	2.04	2.10	2.12	2.13	2.04	2.10	2.13	2.08	2.07	2.11	2.16
	53	1.90	1.94	1.96	2.02	2.02	2.08	2.10	2.06	2.09	2.11	2.09	2.03	2.03	2.09	2.10	2.09
	51	1.84	1.90	1.99	2.03	2.02	2.03	2.06	2.09	2.11	2.11	2.08	1.98	2.02	2.07	2.07	2.00
	49	1.79	1.81	1.90	1.93	1.99	2.06	2.06	2.08	2.07	2.05	2.02	2.01	2.00	1.99	1.93	1.96
	47	1.72	1.74	1.83	1.89	1.98	2.01	2.05	2.05	1.99	2.00	1.98	1.96	1.91	1.94	1.95	1.92
	45	1.65	1.74	1.82	1.90	1.95	1.96	2.01	1.95	1.95	1.95	1.90	1.89	1.85	1.88	1.90	1.88
	43	1.68	1.78	1.78	1.85	1.87	1.87	1.91	1.85	1.87	1.89	1.89	1.82	1.77	1.79	1.84	1.82
	41	1.80	1.80	1.77	1.85	1.80	1.81	1.83	1.82	1.79	1.84	1.81	1.72	1.73	1.72	1.72	1.72
	39	1.77	1.76	1.75	1.74	1.73	1.72	1.71	1.74	1.75	1.69	1.66	1.58	1.65	1.62	1.59	1.63
	37	1.71	1.69	1.71	1.71	1.68	1.63	1.63	1.71	1.67	1.61	1.52	1.50	1.45	1.51	1.50	1.54

Table B-14: Extreme wave vertical acceleration (RMS) predicted using the Alves and Young's data and a wave simulation (3 days) using the Pierson-Moskowitz spectrum (m/s^2)

Using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 50 year return period, 3 day storm duration

		Longitude															
		W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	1.00	1.00	1.02	1.02	1.02	1.02	1.03	1.03	1.02	1.02	1.04	1.04	1.03	1.02	1.03	1.03
	55	1.00	1.00	1.01	1.01	1.01	1.01	1.03	1.03	1.03	1.01	1.03	1.03	1.02	1.02	1.03	1.04
	53	0.99	1.00	1.00	1.01	1.01	1.02	1.03	1.02	1.02	1.03	1.02	1.01	1.01	1.02	1.03	1.02
	51	0.98	0.99	1.01	1.01	1.01	1.01	1.02	1.02	1.03	1.03	1.02	1.00	1.01	1.02	1.02	1.01
	49	0.97	0.97	0.99	1.00	1.01	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.01	0.99	1.00
	47	0.95	0.96	0.98	0.99	1.00	1.01	1.02	1.02	1.01	1.01	1.00	1.00	0.99	1.00	1.00	0.99
	45	0.94	0.96	0.97	0.99	1.00	1.00	1.01	1.00	1.00	1.00	0.99	0.99	0.98	0.99	0.99	0.99
	43	0.94	0.97	0.96	0.98	0.98	0.98	0.99	0.98	0.98	0.99	0.99	0.97	0.96	0.97	0.98	0.97
	41	0.97	0.97	0.96	0.98	0.97	0.97	0.98	0.97	0.97	0.98	0.97	0.95	0.95	0.95	0.95	0.95
	39	0.96	0.96	0.96	0.96	0.95	0.95	0.95	0.96	0.96	0.95	0.94	0.92	0.94	0.93	0.92	0.93
	37	0.95	0.95	0.95	0.95	0.94	0.93	0.93	0.95	0.94	0.93	0.91	0.90	0.89	0.90	0.90	0.91

Using wave simulation (Pierson-Moskowitz) based on the Alves and Young's extreme Hs data (FT1), 2 x 2 grid, 100 year return period, 3 day storm duration

		Longitude															
		W															
		49	**47**	**45**	**43**	**41**	**39**	**37**	**35**	**33**	**31**	**29**	**27**	**25**	**23**	**21**	**19**
LATITUDE (N)	**57**	1.01	1.01	1.03	1.03	1.03	1.03	1.04	1.04	1.03	1.03	1.05	1.05	1.03	1.03	1.04	1.04
	55	1.01	1.01	1.02	1.02	1.02	1.02	1.04	1.04	1.04	1.02	1.03	1.04	1.03	1.03	1.04	1.04
	53	1.00	1.01	1.01	1.02	1.02	1.03	1.03	1.03	1.03	1.04	1.03	1.02	1.02	1.03	1.04	1.03
	51	0.99	1.00	1.02	1.02	1.02	1.02	1.03	1.03	1.04	1.04	1.03	1.01	1.02	1.03	1.03	1.02
	49	0.98	0.98	1.00	1.00	1.01	1.03	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.00	1.01
	47	0.96	0.97	0.98	1.00	1.01	1.02	1.03	1.03	1.02	1.02	1.01	1.01	1.00	1.01	1.01	1.00
	45	0.95	0.97	0.98	1.00	1.01	1.01	1.02	1.01	1.01	1.01	1.00	1.00	0.99	1.00	1.00	0.99
	43	0.95	0.97	0.97	0.99	0.99	0.99	1.00	0.99	0.99	1.00	1.00	0.98	0.97	0.98	0.99	0.98
	41	0.98	0.98	0.97	0.99	0.98	0.98	0.99	0.98	0.98	0.99	0.98	0.96	0.96	0.96	0.96	0.96
	39	0.97	0.97	0.97	0.97	0.96	0.96	0.96	0.97	0.97	0.96	0.95	0.93	0.95	0.94	0.93	0.94
	37	0.96	0.96	0.96	0.96	0.95	0.94	0.94	0.96	0.95	0.94	0.92	0.91	0.90	0.91	0.91	0.92

Appendix C: Matlab code*

* Because a large amount of Matlab code is used for this study, only the following two Matlab files (M-files) are included in this report: most probable extreme wave prediction and wave simulation. These are not stand-alone files, and in order to run them, other files that are not included in the report are required.

Most probable extreme wave prediction

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% IL HO SUH
%
% October 2006
% Center for Ocean Engineering
% Department of Mechanical Engineering
% Massachusetts Institute of Technology
% Thesis advisor: Prof. Jerome Milgram
%
% Extreme wave prediction (short term extremal) using the Ochi's method
% for a selected mesh size (2x2 or 4x4) and a time period (50 or 100 yrs)
%
% Prof. Milgram's lecture notes (13.76), p180
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [HprobB, HprobO] = SUH_extreme_wave_prediction(mesh, period,...
    latt,longg, la,lo, H, T, s_h, nn, t, al, tint, dist, tsel, perd,...
    f_h, fmode);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if dist == 1;
    distr = 'FT1';
elseif dist == 2;
    distr = 'W2P';
end
d_f = 0.0005; % delta_f
ff = [0.001:d_f:1]; % frequency range, hz
% Calculate Bretschneider Spectrum
[S f alpha beta m_0 m_2] = SUH_bret(T,H,tsel,ff);
eval(['T',int2str(tsel),'=T;']);
eval(['S',int2str(tsel),'=S;']);
eval(['alpha',int2str(tsel),'=alpha;']);
eval(['beta',int2str(tsel),'=beta;']);
% T_modal or T_peak for the Bretschneider spectrum
Smax = max(S);
ind = find(S == Smax);
fm_b = f(ind);
Tm_b = 1/fm_b; % T modal for Bretschneider
mom = m_2/m_0;
Br = m_0; % area under the curve
if tsel == 1;
    mom_0_1 = m_0;
    mom_2_1 = m_2;
elseif tsel == 2;
    mom_0_2 = m_0;
    mom_2_2 = m_2;
end
% Calculate Hurricane-generated sea (Ochi) Spectrum
[Spec fo fi_ochi m_0 m_2] = SUH_ochi(T,H,ff,tsel,t,al);
```

```matlab
% T_modal or T_peak for the Ochi spectrum
Somax = max(Spec);
ind = find(Spec == Somax);
fm_o = f(ind);
Tm_o = 1/fm_o; % T modal for Ochi
Oc = m_0; % Area under the curve
% Calculate Pierson-Moskowitz spectrum
% Pierson-Moskowitz (WOE p100)
ext_hs = H;
g = 9.81;
fo = g/(2*pi*sqrt(ext_hs/0.0213));
sPM = 0.0081*(g^2)*(2*pi)^-4.*f.^-5.*exp(-0.74.*(fo./f).^4);
F = @(f) 0.0081*(g^2)*(2*pi)^-4.*f.^-5.*exp(-0.74.*(fo./f).^4);
Q = quadl(F,f(1),f(end));
% T_modal or T_peak for the P-M spectrum
sPMmax = max(sPM);
ind = find(sPM == sPMmax);
fm_pm = f(ind);
Tm_pm = 1/fm_pm; % T modal for P-M
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The classic method (WOE, p165)
% assuming design storm lasting 3 hours
K = 0.9; % for extreme storms, for fatigue calculations K = 1
H50 = K*H*(4.033-((log(H))/4))^.5;
% The Battjes method (WOE, p169)
H50_B = 1.12*H50;
% The first more advanced method, Seven Stones (WOE, p173)
H50_SS = 0.97*H50_B;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if f_h == 1;
    figure
    set(gcf,'position',[30 30 1200 650])
    if tsel == 1;
        set(gcf,'name', [distr,' at ',int2str(latt),'-',la,' ',...
            int2str(longg),'-',lo,' for ',mesh,' resolution, ',perd,...
            ' yr period using Hs = ',num2str(H,'%3.2f'),...
            ' m & T_mean = ',num2str(T,'%3.2f'),'sec']);
    elseif tsel == 2;
        set(gcf,'name', [distr,' at ',int2str(latt),'-',la,' ',...
            int2str(longg),'-',lo,' for ',mesh,' resolution, ',perd,...
            ' yr period using Hs = ',...
            num2str(H,'%3.2f'),' m & Tp = ',num2str(T,'%3.2f'),'sec']);
    end
    plot(f,S,f,Spec,f,sPM)
    set(gca,'XLim',[0 0.4])
    xlabel('f (Hz)')
    ylabel('Spectral Density (m^2-sec)')
    legend(['Bretschneider, Area = ',num2str(Br,'%4.2f'),...
        'm^2/sec & T modal = ',num2str(Tm_b,'%4.2f'),'sec'],...
        ['Ochi (Mod. JONSWAP), Area = ',num2str(Oc,'%4.2f'),...
        'm^2/sec & T modal = ',num2str(Tm_o,'%4.2f'),'sec'],...
        ['Pierson Moskowitz, Area = ',num2str(Q,'%4.2f'),...
        'm^2/sec & T modal = ',num2str(Tm_pm,'%4.2f'),'sec'],'Location',...
        'SouthOutside')
    % or 'BestOutside'
    title('Wave Spectra Comparison [x-axis: f (Hz)]');
    grid on
    % velocity spectra
    fv = (2.*pi.*f).^2;
    Sv = fv.*S;
    Svspec = fv.*Spec;
    svPM = fv.*sPM;
    figure
    set(gcf,'position',[30 30 1200 650])
    plot(f,Sv,f,Svspec,f,svPM)
    set(gca,'XLim',[0 0.4])
```

```
    xlabel('f (Hz)')
     ylabel('Spectral Density (m^2/sec)')
    legend('Bretschneider','Ochi','Pierson-Moskowitz')
    grid on
    % acceleration spectra
    fv = (2.*pi.*f).^4;
    Sv = fv.*S;
    Svspec = fv.*Spec;
    svPM = fv.*sPM;
    figure
    set(gcf,'position',[30 30 1200 650])
    plot(f,Sv,f,Svspec,f,svPM)
    set(gca,'XLim',[0 0.4])
    xlabel('f (Hz)')
     ylabel('Spectral Density (m^2/sec^3)')
    legend('Bretschneider','Ochi','Pierson-Moskowitz')
    grid on
end
% Save
if f_h == 1;
    if s_h == 1;
        cd ocean_wave_statistics % open the folder to save the figure in
        file = [int2str(latt),'-',la,' ',int2str(longg),'-',lo,...
            ' Spectra ',distr,' ',mesh,' ',perd];
        saveas(gcf,file,fmode)
        cd ..
        close
    end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[output] = SUH_slope_spectrum(f,S,Spec,f_h,distr,latt,la,longg,...
    lo,mesh,perd,H,T,tsel,s_h);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Order Statistics (Ochi)
% Extreme Amplitude of Highest of n Waves (Design Wave)
% (13.76 notes, p177)
% moment calculation (for n<4) for Bretschneider
% non-dimensional wave amplitude (fi), which will be exceeded during
% only 100*al % of wave records, each t seconds long,
% fi_1 using Tm, fi_2 using Tp.
eval(['fi_',int2str(tsel),...
    ' = sqrt(2.*log(((t.*3600)./(2*pi*al)).*sqrt(mom)));']); % t in sec
figure
set(gcf,'position',[30 30 1200 650])
if tsel == 1;
    set(gcf,'name', [distr,' at ',int2str(latt),'-',la,' ',...
        int2str(longg),'-',lo,' for ',mesh,' resolution, ',perd,...
        ' yr period using Hs = ',num2str(H,'%3.2f'),' m & T_mean = ',...
        num2str(T,'%3.2f'),'sec']);
elseif tsel == 2;
    set(gcf,'name', [distr,' at ',int2str(latt),'-',la,' ',...
        int2str(longg),'-',lo,' for ',mesh,' resolution, ',perd,...
        ' yr period using Hs = ',...
        num2str(H,'%3.2f'),' m & Tp = ',num2str(T,'%3.2f'),'sec']);
end
hold on
if tsel == 1;
    plot(t,fi_1,t,fi_ochi)
    ind = find(t == tint);
    fi_1_tint = fi_1(ind);
    plot(tint,fi_1_tint,'*','MarkerSize',12)
    maxx = 2*fi_1_tint*sqrt(mom_0_1);
    a = num2str(fi_1_tint,'%4.4f');
    fi_ochi_tint = fi_ochi(ind);
```

```
    plot(tint,fi_ochi_tint,'+','MarkerSize',12)
    maxxx = 2*fi_ochi_tint*sqrt(m_0);
    b = num2str(fi_ochi_tint,'%4.4f');
elseif tsel == 2;
    plot(t,fi_2,t,fi_ochi)
    ind = find(t == tint);
    fi_2_tint = fi_2(ind);
    plot(tint,fi_2_tint,'*','MarkerSize',12)
    maxx = 2*fi_2_tint*sqrt(mom_0_2);
    a = num2str(fi_2_tint,'%4.4f');
    fi_ochi_tint = fi_ochi(ind);
    plot(tint,fi_ochi_tint,'+','MarkerSize',12)
    maxxx = 2*fi_ochi_tint*sqrt(m_0);
    b = num2str(fi_ochi_tint,'%4.4f');
end
xlabel('Time (hrs)')
ylabel('Non-dimensional Wave Amplitude')
if period == '_50';
    title(['Most Probable Extreme Wave Height for event period = ',...
        int2str(tint),...
        ' hrs (for comparison: H50-classic = ',num2str(H50,'%4.2f'),...
        'm & H50-Battjes = ',num2str(H50_B,'%4.2f'),'m & H50-SS = ',...
        num2str(H50_SS,'%4.2f'),'m)']);
else
    title(['Most Probable Extreme Wave Height for event period = ',...
        int2str(tint),' hrs']);
end
set(gca,'XScale','log')
legend(['Bret max H-prob = ',num2str(maxx,'%3.2f'),'m'],...
    ['Ochi max H-prob = ',num2str(maxxx,'%3.2f'),'m'],'Location',...
    'SouthEast')
grid on
hold off
% Most Probable Extreme Wave Height using the Bretschneider (B)
% and Ochi (O) spectra
HprobB = maxx;
HprobO = maxxx;
% Save
if f_h == 1;
    if s_h == 1;
        cd ocean_wave_statistics % open the folder to save the figure in
        file = [int2str(latt),'-',la,' ',int2str(longg),'-',lo,...
            ' Extreme H ',distr,' ',mesh,' ',perd];
        saveas(gcf,file,fmode)
        cd ..
        close
    end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if f_h == 1;
        output = SUH_dir_spectra(T,H,tsel,ff,t,al,latt,la,longg,lo,mesh,...
            perd,distr,dist,fmode);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
end
```

Wave simulation

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Original Code by Dr. Jerome Milgram
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Modified by IL H. SUH for thesis work
%
% January 2006
% Center for Ocean Engineering
% Department of Mechanical Engineering
% Massachusetts Institute of Technology
% Thesis advisor: Prof. Jerome Milgram
%
% Wave simulation using the Pierson-Moskowitz spectrum
%
% Pierson-Moskowitz spectrum
% Lecture notes: 13.42 Design Principles for Ocean Engineering
% CH. Ocean Wave Spectra, p6
%
% Tucker, M.J. and Pitt, E.G. "Waves in Ocean Engineering" Elsevier,
% Oxford, U.K. (2001)
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function  [t zeta_max zeta_max_std zeta_max_slope Tz_mean...
    Tz_mean_std Tp_mean H_mean H_max H_max_std lamda_mean lamda_mean2...
    lamda_max lamda_min df ffold vel_RMS vel_sig accel_RMS accel_sig...
    steep_mean] = SUH_wavesimm(ext_hs,T,D);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
global lamda_min N f_h spectrum
if D == 1; % 1 day storm duration
    npts = 34128;
elseif D == 2; % 2 day storm duration
    npts = 68280;
elseif D == 3; % 3 day storm duration
    npts = 102420;
elseif D == 0.125; % 3 hr storm duration
    npts = 4268;
end
g = 9.81; % gravitational constant (m/s^2)
Hs = ext_hs; % extreme significant wave height
df = 1/T;
dt = 1/(npts*df);
nptso2 = npts/2.0;
tr = dt* npts; % dt * npts for "npts" total points
t = 0:dt:(tr-dt);
ffold = df * nptso2; % df * (npts/2) for "npts" total points
freq = 0:df:ffold; % frequency range corresponding to T and f_max
freq = freq+eps;
% Set up the table
wave_amp_data = zeros(N,npts);
wave_amp_max = zeros(N,1); % crest heights only
wave_amp_square = zeros(N,1);
h = zeros(N,1);
h_max = zeros(N,1); % with threshold > ext_hs
Tp = zeros(N,1);
Tz = zeros(N,1);
Tz_PM = zeros(N,1);
Tz_bret = zeros(N,1);
```

```
Tz_ochi = zeros(N,1);
sigH = zeros(N,1);
mean_vel = zeros(N,1);
sig_vel = zeros(N,1);
mean_accel = zeros(N,1);
sig_accel = zeros(N,1);
lam = zeros(N,1);
lam_max = zeros(N,1);
lam_min = zeros(N,1);
for m = 1:N;
    f = 0:df:ffold; % frequency range corresponding to T and f_max
    f = f+eps;
    % Pierson-Moskowitz (WOE p100)
    fo = g/(2*pi*sqrt(ext_hs/0.0213));
    sPM = 0.5*0.0081*(g^2)*(2*pi)^-4.*f.^-5.*exp(-0.74.*(fo./f).^4);
    power = [0 2 4];
    for p = 1:length(power);
        pp = power(p);
        F = @(f) ((2*pi*f).^pp).*0.0081*(g^2)*(2*pi)^-4.*...
            f.^-5.*exp(-0.74.*(fo./f).^4);
        Q(p,1) = quadl(F,f(1),f(end));
    end
    QPM = Q;
    % Pierson-Moskowitz spectrum
    sigH(m,1) = 4*sqrt(Q(1,1));
    RMS_vel(m,1) = sqrt(Q(2,1));
    sig_vel(m,1) = 4.*RMS_vel(m,1);
    RMS_accel(m,1) = sqrt(Q(3,1));
    sig_accel(m,1) = 4.*RMS_accel(m,1);
    Tz_PM(m,1) = 2*pi*sqrt(Q(1,1)/Q(2,1));
    % T_modal or T_peak for the P-M spectrum
    sPMmax = max(sPM);
    ind = find(sPM == sPMmax);
    fm = f(ind);
    % Ochi spectrum
    T = 1/fm;
    tsel = 2; ttt = 1; al = 1; % ttt and al dummy variables in this case
    [sOchi f fi_o m_0 m_2] = SUH_ochi(T,Hs,f,tsel,ttt,al);
    QOchi = m_0;
    sigH(m,1) = 4*sqrt(m_0);
    sOchi = sOchi.*0.5;
    Tz_ochi(m,1) = 2*pi*sqrt(m_0/m_2);
    % Bretschneider spectrum
    T = 1/fm;
    tsel = 2;
    [s Sf alpha beta m_0 m_2] = SUH_bret(T,Hs,tsel,f);
    sBret = s.*0.5;
    QBret = m_0;
    sigH(m,1) = 4*sqrt(m_0);
    Tz_bret(m,1) = 2*pi*sqrt(m_0/m_2);
    %%%%%%%%%%%%%%%%%%%%%%%%%%
    % Select
    s = sPM; % Pierson-Moskowitz
    s = sOchi; % Ochi's hurricane-generated sea spectrum
    s = sBret; % Bretschneider spectrum
    %%%%%%%%%%%%%%%%%%%%%%%%%%
    if f_h == 1;
        if m == 1;
            figure
            set(gcf,'position',[30 30 1200 650])
            plot(f,sBret,f,sOchi,f,sPM)
            xlabel('f (Hz)')
            ylabel('Spectral Density (m^2-sec)')
            legend(['Bretschneider, Area = ',num2str(QBret,'%4.2f'),...
                'm^2/sec'],...
                ['Ochi (Mod. JONSWAP), Area = ',num2str(QOchi,'%4.2f'),...
```

```
            'm^2/sec'],...
            ['Pierson Moskowitz, Area = ',num2str(QPM,'%4.2f'),...
            'm^2/sec'])
        grid on
    end
end
rand ('state',sum(100*clock));
p = 2.0 * pi * rand(1,nptso2);
p(nptso2+1) = 0.0;
z = exp(i*p).* sqrt(s*df);
zt = [z  conj(fliplr(z(2:npts/2)))];
% FFT
zeta = real(fft(zt));
ampsq = zeta.^2;
wave_amp_data(m,:) = zeta;
wave_amp_max(m,1) = max(zeta); % crest heights only
wave_amp_square(m,1) = mean(ampsq);
% wave_amp_max(m,1) = max(abs(zeta)); % both crest and trough
% local maxima & minima
a = zeta;
%
down = a > 0;
Y = diff(down);
downi = find(Y<0); % crest to trough (+ to -)
up = a < 0;
YY = diff(up);
upi = find(YY<0); % trough to crest (- to +)
if upi(1) > downi(1);
    first = downi;
    second = upi;
    c = second(1:end)+1;
    d = first(2:end);
    e = d+1;
    f = c(2:end)-1;
elseif upi(1) < downi(1);
    first = upi;
    second = downi;
    c = first(1:end)+1;
    d = second(1:end);
    e = d+1;
    f = c(2:end)-1;
end
l = length(c);
one_per = zeros(1,l-1);
one_max = zeros (1,l-1);
two_per = zeros (1,l-1);
two_max = zeros (1,l-1);
zc = zeros(1,l-1);
for mm = 1:l-1;
    one_b = (c(mm):d(mm)); % data boundary 1
    wave = max(a(one_b(1):one_b(end)));
    ind = find(a(one_b) == wave);
    crest_per(mm) = t(one_b(ind));
    crest_max(mm)= a(one_b(ind));
    two_b = (e(mm):f(mm)); % data boundary 2
    wave = min(a(two_b(1):two_b(end)));
    ind = find(a(two_b) == wave);
    trough_per(mm) = t(two_b(ind));
    trough_min(mm)= a(two_b(ind));
    %
    three_b = (c(mm)-1:c(mm)); % data boundary 3
    zc(mm) = interp1(a(three_b),t(three_b),0);% zero-crossing
end
%
lc = length(crest_max);
T = zeros(1,lc);
```

```
    wh = zeros(1,lc);
    lamda = zeros(1,lc);
    steepness = zeros(1,lc);
    for nn = 2:lc
        % wave height (crest to trough)
        wh(nn) = crest_max(nn) + abs(mean([trough_min(nn-1)...
            trough_min(nn)]));
        % wave period (based on trough peaks)
        T(nn) = trough_per(nn)-trough_per(nn-1);
        % wave length
        % lamda(nn) = (g*(T(nn-1)^2))/(2*pi);
        lamda(nn) = (g*(T(nn)^2))/(2*pi);
        steepness(nn) = wh(nn)/lamda(nn);
    end
    lz = length(zc);
    Tzero = zeros(1,lz);
    for n = 2:lz;
        % zero-crossing wave period, Tz
        Tzero(n) = zc(n)-zc(n-1);
    end
    Tp(m,1) = mean(T);
    Tz(m,1) = mean(Tzero);
    threshold = find(wh > ext_hs & steepness < 0.143); % WOE, p42
    h(m,1) = mean(wh(threshold));
    h_max(m,1) = max(wh(threshold));
    lam(m,1) = mean(lamda(threshold));
    lam_max(m,1) = max(lamda(threshold));
    lam_min(m,1) = min(lamda(threshold));
    steep_max(m,1) = max(steepness(threshold));
    lamm(m,1) = mean(lamda);
end
% Outputs
H_mean = mean(h); % mean wave height (crest to trough that exceeds Hs)
H_max = mean(h_max); % maximum wave height
H_max_std = std(h_max); % standard deviation of H max
lamda_mean = mean(lam); % mean wave length exceeding threshold
lamda_mean2 = mean(lamm); % mean wave length
lamda_max = mean(lam_max); % max wave length exceeding threshold
lamda_min = mean(lam_min); % min wave length exceeding threshold
zeta_max = mean(wave_amp_max); % maximum wave amplitude (crest)
zeta_max_std = std(wave_amp_max); % standard deviation of zeta max
zeta_max_slope = 0; % not calculate here for now
Tp_mean = mean(Tp); % mean peak wave period
Tz_mean = mean(Tz) % mean zero-crossing period
Tz_PM_mean = mean(Tz_PM); % mean zero-crossing period PM
Tz_bret_mean = mean(Tz_bret); % mean zero-crossing period Bretschneider
Tz_ochi_mean = mean(Tz_ochi); % mean zero-crossing period Ochi
Tz_mean_std = std(Tz); % standard deviation of Tz mean
vel_RMS = mean(RMS_vel); % mean vertical velocity
vel_sig = mean(sig_vel); % significant vertical velocity
accel_RMS = mean(RMS_accel); % mean vertical acceleration
accel_sig = mean(sig_accel); % significant vertical acceleration
steep_mean = mean(steep_max); % mean steepness ratio
%
%The above gives same results as zeta = npts*real(ifft(zt))
%
if f_h == 1;
    figure
    set(gcf,'position',[50 100 1200 500])
    plot (t,zeta);
    xlabel('TIME (sec)')
    ylabel('SURFACE ELEVATION (m)');
    title('Simulated Sea Waves at a Point');
end
%
end
```